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NERVES

BY

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TO

THE MEMORY OF

MY FATHER

I DEDICATE THIS BOOK

PREFACE

The following pages express in a sense a pioneer effort; they attempt to explain in non-technical language the place and powers of the nervous system. They do not form an essay in physiology, because the activities of only one great system of the body are discussed. Nor do they deal with psychology —the science of consciousness and behaviour— for that is the subject of another volume of this library.

What follows is an exposition, limited as to its space and illustration, of the capabilities and peculiarities of the nervous system, more particularly of those regions whose activities are not associated with the rousing of consciousness.

It is hoped that those whose previous knowledge of physiology and psychology is small may learn something of the way in which this complicated system does its work; and that those who happen to know something of these subjects may yet gain more

from an account of innervation, which is as accurate as popular terminology allows it to be. The student of the nervous system will find the general principles discussed with some thoroughness, he may even find explained certain neural activities which the systematic text-books pass lightly over.

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NERVES

CHAPTER I

HOW THE NERVES WORK

Possibly no terms are more frequently used in ordinary conversation than "nerves" and "nervousness." Even the nervous system is alluded to with a degree of familiarity which would betoken a knowledge of its workings very much greater than we have reason to believe the speaker possesses. Owing to the prevailing ignorance about the nervous system, the quack and the charlatan have made much gain out of nerves and nervousness.

Before we can understand what nervousness means, what a nervous person is, and in what an attack of nerves consists, we shall have to ponder a little on what the healthy nervous system is and how it works under normal conditions. The detailed study of the nervous system needs, perhaps, greater skill and patience than that of any other of

the bodily systems ; the specialist who studies it we call a neurologist. The nerves and the nerve-cells are hidden and inaccessible, they require special and uncommon methods to prepare them for microscopical inspection, and the experimental procedures for following the nerve-paths into, up and out of the nervous system are very difficult to practise. But without all this training, intelligent people are able to learn a good deal of the way in which the nervous system works, and to appreciate the large place which nerves fill in the life of to-day. Just as we do not need to understand the details of the construction of a flying-machine to take an interest in aviation, just as we can follow a naval battle without knowing how to construct a torpedo, so we may glean some facts as to how the nerves do their work without being anatomists, neurologists, or physiologists.

We cannot complain that the nerves are not recognised as playing a part in life: we speak of a person being nervous, being "nervy," or as having highly strung nerves. Brainless is a term that has been long in use; and the Americans have introduced "brainy." A style of writing is described as nervous.

A person is said to be of iron nerve or of no nerve at all, another has strong nerves or weak nerves or a nervous system in a state of tension, as the case may be. Nor is this popular recognition of the place and power of the nervous system based on any misconception of its attributes ; it is not too much to say that what we call our life—our pleasures and pains, hopes and fears, propensities, weaknesses, fancies, memories and accomplishments—are dependent in the most literal way on the activity, healthy or otherwise, of the nervous system. Even what used to be called our " vegetative " life, the life of the heart, the digestive and other internal organs, is also dependent to a degree of which previously we had no adequate notion upon the well-being of our nerves and nerve-centres. An immense number of the activities of the nervous system are entirely outside the realm of consciousness. Strictly speaking, psychology deals only with our conscious life, physiology deals with the normal working of every organ we possess, but we may profitably look into nerves and their workings without trespassing on psychology and even without any very special knowledge of physiology. The volumes on both these subjects in this

Library are, however, strongly recommended to the reader.

Every one knows that the nervous system into which and out of which the nerves run, is hidden away inside the skull, and in the cavity of what is called the backbone (series of vertebræ). The spinal cord occupies the cavity of the latter, the brain (cerebrum) and cerebellum fill the former. (See Fig. A.) The brain and the spinal cord are connected by what one may call the brain-stem, which by anatomists is divided for descriptive purposes into certain regions the names of which do not concern us. Since the brain is composed of two halves or hemispheres, and each half is connected to the brain-stem, it is plain that the brain-stem at its front end must be double. The totality of fibres from each half of the brain is called the cerebral peduncle; the two peduncles fuse together to form the common brain-stem, which, before it becomes the spinal cord, swells out into a region known as the medulla oblongata. Here are situated many of the most important nerve-centres, or collections of nerve-cells, superintending such bodily activities as breathing, the heart's action, the regulation of the size of the blood-vessels, perspiration, the flow of saliva, the

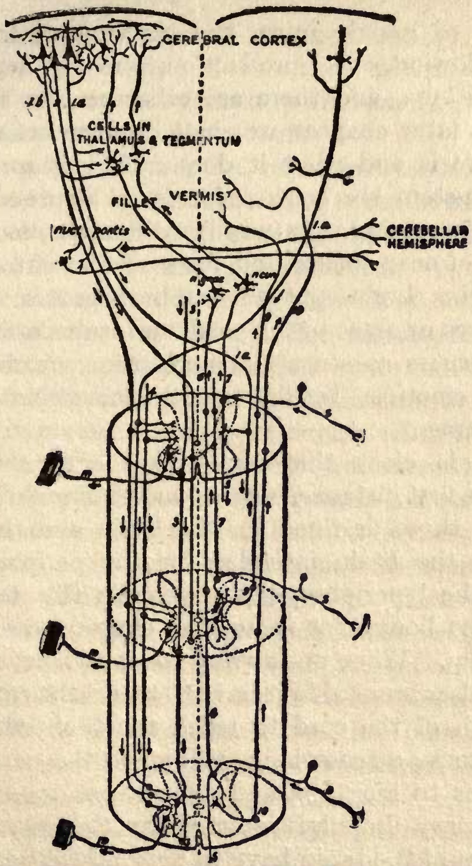

FIG. A—Diagram of the entire Central Nervous System. The dotted line is in the mid plane. Nerves entering the spinal cord are on the right, those leaving it are on the left. The place marked Fillet is in the Peduncle of Brain. The cerebellum is indicated in its crossed relation to the cerebrum. [By permission from Sir E. A. Schäfer's "Essentials of Histology" (Longmans).]

flow of gastric juice, the chewing of food, swallowing, voice-production, and the act of vomiting: and there are other centres still. In a later chapter we shall discover what a centre is and what it does. Higher up the brain-stem are centres for facial expression, eye movement, iris (pupil) movements, focussing of near objects and the secretion of tears. In the brain proper cerebral cortex are centres or areas underlying such states of consciousness as sensation, perception, memory, and emotion, besides speech and voluntary movement.

It is clear that the spinal cord must, in the first instance, be a conductor of impulses, both those destined for the brain and those from the brain intended for the periphery. By the "periphery" we mean in this sense all the body that is not the central nervous system. When one's great toe is tickled, the impulses aroused in it have to travel the entire length of the cord to reach the brain there to arouse a sensation; and when the person wishes to kick out and so use that toe, the necessary impulses started in the highest region of the brain have to descend the whole length of the cord to reach the muscles that are to become active. The cord is, therefore,

a conductor upwards of impulses that will arouse sensations, downwards of impulses that will arouse voluntary movements, and of many other kinds as well.

The spinal cord, is, however, something more than a conductor or transmitter of impulses; it is also a collection of centres in series from above downwards. Nerves enter the cord and nerves leave it at certain levels all the way down. The ingoing nerve and the outgoing nerve are anatomically and functionally linked in the interior of the cord; this place is called a centre (see Fig. I.).

A centre on its structural side consists of at least one cell on or over which the ending of a nerve fibre is distributed; usually, of course, many cells go to make up a single centre. The ingoing nerve, whose backward branch (E) ends on the centre, also sends a headward branch (D) towards the regions of consciousness. Thus it is that when a pin is stuck into our hand, we feel the pain and jerk back the hand practically at the same instant; we feel the pain because of the impulses that reach the brain over the upward extension (D) of the incoming spinal nerve, and we jerk the hand away because of the impulses that reach the centre through the

backward branch (E) of the nerve. The jerking is carried out by the mechanism of a spinal cord centre, the sensation is aroused through a brain centre, but the two are intimately linked together. The spinal mechanism for jerking is the type of *a reflex nerve-arc and reflex centre*, the cerebral mechanism is a loop or upper outgrowth (D) from the lower reflex spinal mechanism. In order to arouse consciousness, the looped extension must be traversed by the impulses; the jerking could be carried out in the absence of all sensation, in which case only the lower or reflex nerve-arc would be used.

Now it is very natural to ask at this point what exactly is the nervous system for. We know what some of the other systems are for —the circulatory system is for sending blood round the body, the digestive for absorbing food, the excretory for getting rid of waste material, but what, in a few words, is the nervous system for? It is first of all for carrying out certain activities, such as breathing, on a subconscious plane, over which the constant supervision of consciousness would be tedious if it were not impossible considering the enormous number of demands made on the attention of the individual. It is,

in the next place, for carrying out certain activities with the greatest possible speed compatible with the greatest possible accuracy;

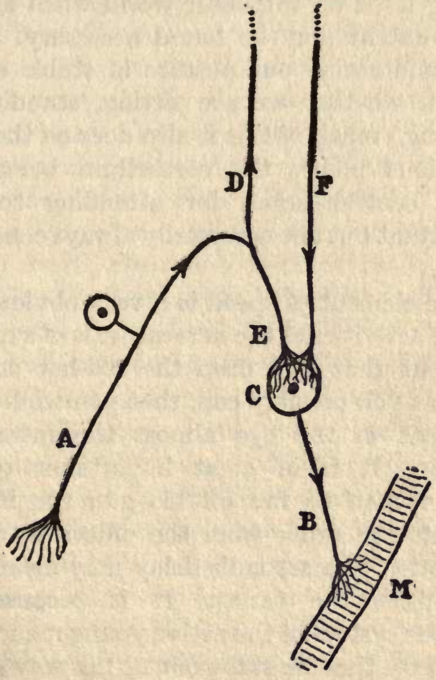

FIG. I.—A is an incoming nerve, B an outgoing. E is a backward branch of A, D is a forward branch. A may commence in the skin, B ends on a muscle (M), C is a centre. F is a nerve-fibre descending on the centre.

it is for linking up functionally the outer world with our living bodies, allowing it to act on our bodies within certain limits, and reversely acting itself on the outer world when and to what extent may be found necessary. It is for maintaining our posture in stable equilibrium, whether we are sitting, standing or walking, much of this it also does on the subconscious plane, the cerebellum being the great central organ for attending to this important but not necessarily always conscious affair.

The element of speed is a very obvious one in the activities of the nerves ; it is of supreme moment that you drop the red-hot coal as soon as you possibly can, that you wink away the grit in the eye almost the instant it alights. It is of great importance to the artilleryman to fire off his gun the instant he gets the order from the officer to do so, a fraction of a second's delay may mean that he misses the target. It is because the nervous system of the active young man works promptly that he skips out of the way of the motor car, whereas the old gentleman with his much more slowly acting one may be run over. If you are too slow at taking the " service " at tennis, you will miss the ball.

If too quick the same result will happen: through the nervous system one is taught exactly how quick to be. That the element of speed is definitely neural is rather interestingly brought out in connection with the recent work on the function of digestion. It has been shown that the outflowing of gastric juice is brought about by two different mechanisms, one acting through the nerves, the other of a chemical character. The former, the neural, acts at once as when we see or smell, chew and swallow food; these sensations and activities call forth a flow of juice with very little delay. But gastric juice continues to be secreted for hours after we have ceased to see or smell or chew the food, and this, the second process, is a chemical and a much slower one. The nervous system makes immediate provision that some juice will be ready to receive the food, but the flow of juice has to be kept going for long after the reception of the food, and this slow affair is not neural. Neural activities are for emergencies by quick responses, while there are chemical activities in the body that are of a far more abiding but unconscious order.

But the nervous system attends to other matters than mere speed; it cares for accuracy

too. Thus at tennis not only must I strike the ball at the right instant, but at the proper spot of my racket, not the handle, not the wood. The muscular adjustments necessary to bring the centre of the racket in contact with the flying ball are carried out by *co-ordination.* A large number of muscular activities have to be co-ordinated to bring about any desired activity; many, perhaps widely separated, muscular groups have to be brought into simultaneous contraction, made synergic (or co-operative), while other muscular groups require to have their activities restrained. The carrying out of all these things in due order is known as neuro-muscular co-ordination. All games of skill, for instance, billiards, gymnastics up to trapeze displays, and tight-rope walking, involve this co-ordination. The nervous system is the essential in co-ordination, whether it be in the baker's boy balancing his bread-board on his head, or in Cinquevalli balancing two billiard balls on the top of a cue on the end of his nose. Supreme accuracy of muscular adjustment it is that underlies all these different performances, but in smaller degrees we all employ it, as we are bound to do. We co-ordinate our muscles to step out of a carriage on to the ground, to ride on

horseback, to ride a bicycle, to steer a motor car, to use a typewriting machine, and so on.

Besides accuracy of adjustment there is the element of the precise amount of force to put into the muscles. This putting forth the exact amount of force—neither too much nor too little—is called *eumetria*, which means the exact or right measure (of force). Thus not only must the tennis ball be struck at the right instant with the right spot of the racket, but it must be struck with the proper amount of force in order to be returned "within court." The nervous system as a rule learns the exercise of this eumetria by slow and painful experience. Eumetria enters into nearly all that we do. We must use the exact amount of force in order to accomplish any result with accuracy. In ordinary walking we learn to put forth exactly the necessary amount of energy, neither stamping heavily on the pavement nor putting down our feet so feebly that we would make no progress at all.

The engraver, the wood-carver, the watchmaker, and a hundred other skilled workmen, are skilled because they have learned eumetria. The man who would go to mend his watch with the force of a man raising a stone with a

crowbar, has not learned eumetria, and if he never could learn it, he never could become a skilled workman. The skilled workman thinks that he should be rewarded by good wages for his skill in having learned eumetria; the unskilled labourer who cannot learn it need not expect to get the same wages as a skilled man. His nervous system is not worth so much; perhaps he cannot learn the necessary fineness of muscular adjustments, eumetria and co-ordination, cannot perhaps by reason of inherited disability, and society at present does not pay him so much as it does his more fortunate brother. All men are not equal, either at birth or by training: all nervous systems are not equal; and he who asserts that they are utters a neurological inexactitude.

But it is very clear that all this precision, co-ordination, and expenditure of the correct degree of muscular energy is only possible in proportion as the muscular and other senses are properly trained. Unless the man has acquired a fine perception of resistance—the chief kind of information yielded by the muscular sense—he cannot duly grade the intensity of the output of his muscular efforts. The engraver must learn exactly how much

force to employ with the graving-tool upon the steel or copper; the artilleryman must have very good eyesight to notice the exact moment when the bows of the target-ship cross the hair lines in his telescopic sights. Thus the training of the senses should be a large part of education. It was by muscle reading, not thought-reading, that the late Mr. Stewart Cumberland could tell exactly where an object was hidden so long as he held, pressed firmly against his forehead, the hand of a person who knew the secret. Certain thrills told him "you are right"; others "you are wrong," but had his nervous system not been finely attuned to muscular sensations he would never have had the success which he achieved.

We see, then, that the nervous system puts us into communication with the outer world and its inhabitants which act on us, enables us with speed, accuracy and the correct amount of force to react upon it, and then it makes us aware of our own bodily states, and enables us to adjust our bodily position to the changing states of the environment. In our nervous system we store memories of what has happened, we register experience for the future. we communicate, as we will,

with our fellow-beings and, maintaining our self-conscious identity, we continue our conscious connection with the past. Nerves and the nervous system not only protect the individual from injury, enabling him to seek food, avoid or overcome enemies; but they are constantly handing over some activity or other from the conscious to the subconscious realm. We educate the nervous system laboriously to perform certain actions, conscious attention being very much concerned in the acquisitions, but by degrees these acquisitions are relegated to the unconscious or at least subconscious realm and are at last carried on without the interposition of attention at all. There is a very great saving of nerve energy here; things so done are called habits. Such co-ordinated activities as the maintenance of posture in walking are, in this way, carried on below the conscious level, so that as we walk alone we can be engaged in solving a problem, or if with a friend we can carry on a conversation without having to give any attention to the movements of the limbs. Even talking can become an automatic affair of this kind, as when we recite a poem without thinking of each word, and what comes after it, as we had to do when

we learnt it originally. Habit is the popular word for all those activities which may or may not have been originally learned, but which are now all relegated to the subconscious sphere. "Instinct" is the popular term for habit as found congenitally present. We say that a child knows how to suck by instinct; certainly it is not by consciousness, for children without brains at all (acephalic monsters) can suck perfectly. The child inherits the capability of carrying out the co-ordinated movements of sucking: it does not require to learn these, they are potentially present in its nervous system. We shall later see that this sort of thing is only an example of a certain kind of reflex action.

One of the best illustrations of how the nerves work is the one so often given, the telephone exchange. What is a telephone exchange for? To put two people into (verbal) communication with each other. A wants to speak to B, and in order to do this he asks the exchange or central to connect him with B. Let us call the central C. Now A is connected to B through the intermediation of C, without which he never could be. Electric currents pass from A to C and from C to B, and so B is made aware of what

A wants with him. Now all this is an analogy with what goes on in the nervous system. Let us suppose that A is a spot of skin into which a pin has been stuck, and B is a certain group of muscles some distance from A. The pained spot A sends an urgent message up the nerves to a number of nerve-cells, or to what is called the centre, and from these, roused in this way to activity, issue outgoing currents to the muscles of the group whose contraction constitutes the kick or jerk which the leg or arm gives as the result of that sudden pinprick. Nerve-currents have ascended nerve-fibres or gone in from A, they have aroused a centre C to action, and the centre has discharged nerve-impulses by other nerves to the muscles thrown into activity at B. We see, then, in the first instance, that nerves can convey impulses or at any rate *something*, from the surface of the body into the nervous system, and, in the next place, that they can carry something out from the nervous system to the muscles at the periphery. Nerve-fibres which convey impulses inwards are called *afferent* nerves, and nerves which convey impulses outwards are called *efferent*. Afferent, or ingoing, and efferent, or outgoing, have reference exclusively to the central

nervous system. Just as when we are in England, we talk of the "up" line, meaning the line to London wherever it may happen to start, and of the "down" line as the one out of London wherever it may happen to go; so in the body, afferent nerves mean those carrying impulses into the central nervous system, and efferent those carrying impulses out. It comes to this, that afferent nerves are those whose impulses pass from anywhere at the periphery to the central nervous system, and, conversely, efferent are those whose impulses pass from the central nervous system to anywhere at the periphery. Afferent impulses impinge on a centre which is thereby roused to activity, efferent impulses are poured out into muscles or blood-vessels or glands, as the case may be, that is, they influence or *innervate* different tissues and organs at the periphery.

Now just as A has, at any rate in theory, the right or power to speak not only to B, but to any one else on that particular exchange, so in the central nervous system the currents from C can go to a very large number of other regions of the periphery. The painful stab of the pin may make one man kick, another blush, another blanch, a fourth perspire,

a fifth groan, a sixth sigh, or a seventh swear. It would largely depend on the particular centre to which the afferent current happened to have spread. Or one man might do some three or four of these things at once. Thus, as the result of entry by one afferent path, a large number of different efferent paths might be opened up. Here the analogy of the telephone breaks down, for whereas as a result of the stimulation of the region A, a large number of different parts of the periphery may be simultaneously roused to action, A cannot speak through the telephone to more than one subscriber at once.

CHAPTER II

NERVE-FIBRES AND NERVE-IMPULSES

THE nerve-fibres themselves are perhaps the least striking of the bodily tissues as viewed under the microscope. A nerve-trunk is not at all unlike a tendon, a long, white, tough cord, so like it that the ancient Greeks did not distinguish the two and called both nerves and sinews, neura. The great majority of nerves are those called medullated, those provided with an insulating sheath, a fatty substance which in life is of semi-solid consistency. This fatty substance may be regarded as an insulator surrounding a central core or axis, a most delicate thread which takes origin in a nerve-cell somewhere. The medullated nerve-fibre is therefore a minute cylinder of fatty sheath surrounding the true conducting substance, and it resembles, in some respects, an electric wire inside its insulator. The central core which conducts the nerve impulses answers to the wire itself,

the fatty sheath corresponds to the insulating cover of cotton, silk, gutta-percha, or the like. A large number of these fibres are bound up together to form a nerve-trunk exactly as a large number of wires are placed together to form a cable.

Now there is a second kind of nerve-fibre, the non-medullated, which has no fatty sheath; but we cannot suppose that there is faulty insulation of impulses in such fibres. For we find that a fibre conveying impulses may begin as non-medullated, become medullated, and end non-medullated, and we know that much important innervation of internal organs is carried out by means of these unsheathed, non-fatty fibres. Now a nerve-fibre by itself in the body would be like a railway line that began at no station and ended at no station. It would be useless for the purposes for which a railway is designed. The nerve must begin somewhere and end somewhere else, for it has to conduct impulses either into or out of the nervous system. In a certain sense, nerves do nothing more than this. The cell of origin of the nerve-fibre, and the fibre and all its processes and ramifications is now known as a *neurone*. There are three great classes of neurones: afferent, those which

begin in the tissues and organs; those which never leave the nervous system (the internuncial); and the efferent, those which end in the tissues and organs. (See Fig. II.)

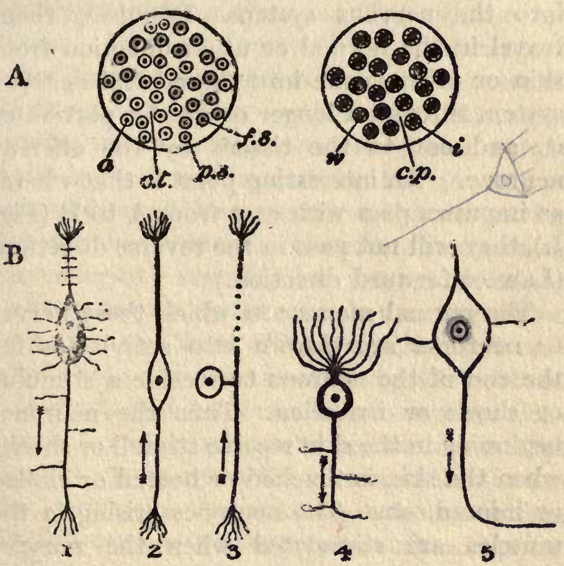

FIG. II.—A. Transverse sections of nerve and of electric cable compared. *a.*, axis-cylinder; *f.s.*, fatty sheath; *p.s.*, primitive sheath; *c.t.*, connective tissue packing; *w.*, the wire; *i.*, its insulation; *c.p.*, cement packing.
B. Types of neurones or nerve-cells. 1, from the brain; 2, from nerve of hearing; 3, from nerve of touch; 4, from cerebellum; 5, from spinal cord for motor nerve. The arrow shows direction of impulses.

The fibres of the internuncial and efferent neurones began in cells ; the afferent neurone also began in a cell which sent one fibre down to the skin or other tissue, and the other fibre into the nervous system. Impulses, then, travel in the normal or usual direction from skin or other tissue into the central nervous system through a longer or shorter portion of it, and out to the tissues by the efferent neurone. An interesting point is that whereas impulses pass with ease from A to B (Fig. I.), they will not pass in the reverse direction. (Law of forward direction.)

The normal manner in which these nerves or neurones are thrown into activity is for the end of the neurone to receive a stimulus or shock or irritation. Thus the neurones beginning in the skin receive stimuli or shocks when the skin is touched or heated or chilled or injured, etc. The neurones arising in the muscles are stimulated when the muscles squeeze upon the special origins of these fibres ; the neurones arising in the eye are stimulated when light falls into the eye, and so on ; but in all cases only nerve-impulses (whatever they may be) travel into the nervous system. The usual stimulations of afferent nerves are the activity of certain

forms of "external" energy—pressure, thermic change, light, sound, etc., in other words, the afferent nerves are related either to environmental changes or to changes of bodily condition; these constitute the stimulation. In afferent nerve-fibres what happens after stimulation is that nerve-impulses ascend. Nothing, therefore, except nerve-impulses arrives in the central nervous system, so that only nerve-impulses can be the sources of stimulation of the neurones within or leaving the nervous system. Therefore the normal, physiological stimuli for neurones arising in the nervous system are exclusively nerve-impulses, and these affect only the nerve-*cells* which give origin to the outgoing nerve-fibres.

Now it will be seen that, normally, both afferent and efferent neurones are stimulated only at their origins, the former in the tissues, the latter in the central nervous system. If, however, either sort of neurone happens to be stimulated (irritated) at any point in its path, nerve-impulses will ascend or descend the neurone just as though it had been stimulated at its origin under normal conditions. Thus, if I get a blow on my elbow just where the sensory nerve from the fingers is near the surface, I have a distinct sensation

of tingling in the ring and little fingers, the places supplied by the nerve-trunk which has been struck. This is because, although the stimulation has been in the course of the neurone instead of at its origin, only nerve-impulses have ascended to the place in the brain where these neurones end; and the brain, receiving only nerve-impulses identical, so far as it is concerned, with many that had for years come to it from the fingers, interprets these abnormal ones as having still come from the fingers. This is on the sensory side an example of the result of stimulating an afferent nerve in its course (heterologous stimulation). The psychologist calls the conscious result, an illusion. A blow on the eye, giving rise to flashes of light, and a "box" on the ear, giving rise to singing in the head, are examples of unphysiological stimulation of sensory end-organs rather than of nerves.

The results of stimulating an outgoing (motor) neurone in its course depend on the kind of tissue or organ in which the nerve ends. Thus, if the nerve to a muscle be stimulated, not at its cell of origin but at any point in its course, muscular contractions will result; if it be a nerve to a blood-vessel, the vessel will lessen or widen its diameter,

as the case may be ; if it ends in a gland, the gland will secrete and so on. Thus, when we apply a battery to the skin, so that the electricity reaches the nerves below, we find that the muscles are made to twitch. As examples of abnormal stimulation of efferent nerves, we have such conditions as a tumour pressing on the trunk of the outgoing nerve to the muscles of the face, whereby these are set twitching. Inflammations of the sheaths of muscular nerves also cause twitchings. A spur of bone growing out from the bony aperture through which a muscular nerve leaves the skull or vertebral column, is by no means an uncommon source of this sort of thing ; the muscles supplied go into abnormal activity.

We might now ask ourselves whether we know anything about the speed with which the nerve-impulses ascend towards or descend from the nervous system. What is the velocity of propagation of impulses in the nerve-fibres ? The problem is easier of solution in the case of the outgoing than in the case of the ingoing nerves, because impulses in the outgoing nerves can produce some sort of visible activity while those in afferent nerves do not ; but it has been measured in both

sorts of nerves by more than one kind of method, and been shown to be by no means of an incalculable or infinitely great order of velocity. For a long time nerve-energy, as nerve-impulses were called, was thought of as identical with electric energy. At the time when the fundamental phenomena of electricity had just been discovered by Galvani and Volta in Italy, it was natural to conclude that nerve-energy was either the same as electricity or acted with a similar speed. For indeed neural operations seemed to be carried out with the speed of lightning. The "twinkling of an eye" had always meant something inconceivably short, the speed of thought was a synonym for what was brief indeed. So eminent and cautious a physiologist as Johannes Müller wrote as lately as 1835—"We shall probably never attain the power of measuring the velocity of nervous action, for we have not the opportunity of comparing its propagation through immense spaces as we have in the case of light." Within fifteen years after this prophecy was made, a fellow-countryman of Müller, the great mathematical physicist and physiologist, Hermann von Helmholtz, then Professor of Physiology at Königsberg, measured

the rapidity of the propagation of the nerve-impulse in one of the motor nerves of the frog, and found it something, relatively speaking, of quite a low order of velocity, namely, ninety feet (thirty metres) a second. Helmholtz also measured the rate in a motor nerve of man by stimulating a nerve through the skin at the elbow (A) and again at the wrist (B), and subtracting the times that elapsed, respectively, before the muscle of the thumb jerked the recording lever. Suppose that the distance from A to B is twelve inches, and that the impulse took 150th of a second to travel that distance, then the velocity is clearly 150 feet a second. It may be as much as 180 in the motor nerves of man. This is by no means an excessive speed. If we harpooned the tail of a whale 150 feet long, it would take one second for the impulses to reach its brain and so make it aware of the pain, and it would take about another second for the animal to send a message to its tail muscles to lash out at the boat. But two seconds are, for some purposes, quite a long time; it doesn't take two seconds to close the eyelids when you see an insect rushing at your eyes. The men of science of the day were by no means prepared for this compara-

tively slow rate of propagation of the nerve-impulse, and its publication aroused a good deal of interest especially amongst those who had held the view that it must be of the speed of lightning.

The power of propagating nerve-impulses is known as conductivity, which is just one word for the expression, the property of conducting impulses. A telegraph wire has electric conductivity, so a nerve-fibre has neural conductivity, but whereas conductivity for electricity or heat is a purely physical affair, conductivity for nerve-impulses is a property of the living matter of the nerve. The only part of the nerve which conducts is the central core or neuraxon (axis-cylinder). In saying this we do not assert that the insulating sheath is not also alive, but if it is alive, it is not so intensely alive, and is not so very highly specialised as the central core or conducting path. All living cells, being living protoplasm, have more or less of this property of conductivity, that is, if stimulated at one spot they send the consequent state of excitement from that spot to others farther off. Muscle, for instance, does this; but besides having conductivity, it has contractility and the power

of heat-production and other manifestations of livingness. Nerve-fibre has, as it were, almost entirely given up the possession of these properties, and retained in an especial degree the property of conducting impulses from point to point throughout its length. Just as the telegraph or the telephone wires are for nothing else than conducting electricity, so the nerves are for nothing else than conducting impulses.

We have arrived at this, then, that conductivity is an expression of the life of the neurone; and if so, we should expect it to be influenced by certain conditions which influence other kinds of living matter. One of the conditions which influences living matter very markedly is temperature, a rise accelerating, a fall retarding manifestations of livingness. Thus while in frogs' nerves the velocity of conduction is thirty metres a second at 17° centigrade, it is as much as sixty-five at 35° C., or more than twice as fast. But once more, livingness does not express itself with equal intensity in all sorts of animals: there are lowly, sluggish animals, and there are high and alert animals. Now it is exceedingly interesting that the rate of propagation of nerve-impulses should vary

according to the kind of temperament of the animal observed. Thus it is much slower in cold-blooded than in warm-blooded animals; in the frog it is slower than in man, although if the frog be warmed to the temperature of the man, the speed is not very different from the speed in human nerves (sixty metres a second). If we take quite a lowly animal like the fresh-water mussel, we find the speed of nerve-impulse is only two and a half inches a second; in *Eledone moschata*, one of the cuttlefishes, it is in winter three feet a second, while in Octopus it is in summer between nine and fifteen feet a second. As a phenomenon of vitality, it varies throughout the animal kingdom as the intensity of vitality varies.

One should here note that although afferent nerves normally conduct from the periphery in towards the centres, and efferent nerves in the reverse direction, yet each kind of nerve, if stimulated in its course, will conduct in both directions, that is, down in afferent and up in efferent nerves. This is called the law of double conduction; it does not break the law that impulses will not pass from an efferent neurone to an afferent one; this "valve-action" applies to the

junction of one neurone with another—the synapsis (C in Fig. I.).

The property of conductivity may be still further studied with profit as giving us insight into the manner of working of the nerves. For instance, if we freeze an inch or two of a nerve, we find that the frozen region will not conduct impulses; it acts as a functional block as completely as would a piece of string tied tightly round the nerve (a ligature). If the frozen region or the ligature were on a sensory nerve, no afferent impulses could ascend, and there would be a diminution or abolition of sensation as the case may be; if on an efferent nerve, no outgoing impulses could descend, and the muscles would become flaccid and paralysed. The application of certain drugs and chemicals, especially narcotic vapours, reduces or abolishes the conductivity according to the strength employed. Thus the vapours of chloroform, ether and alcohol reduce the velocity of the nerve-impulses and in higher concentrations abolish the conductivity altogether.

Many arguments had to be brought forward before men of science gave up the notion that nerve-impulses and electricity were identical. One reason for this may have been the fact

that the passage of nerve-impulses along the conductors is always accompanied by electric currents. This again is a phenomenon not confined to neural tissue, for active muscle does the same thing more intensely. But it is a striking fact that each nerve-impulse is accompanied by an electric wave, and so constant is this that the electric wave is taken as the sign of the passing of a nerve-impulse. But the nerve-impulse is not the same thing as its electric accompaniment, the electric wave is the sign of the existence of the impulse just as the electricity developed by rubbing the cat's skin is not the same thing as the rubbing.

Just as you cannot have muscular contraction without heat, so you cannot have the passage of nerve-impulses without the production of electric current, but they are two different things. One good argument that they are two things is, that if a nerve be heated to about 50° C., its substance will coagulate, and it will have lost all its neural conductivity but not its electrical conductivity. If, then, it cannot transmit nerve-impulses but can still transmit electric current, nerve-impulses cannot in themselves be electricity. Again, the frozen nerve will conduct

electricity but not nerve-impulses, as we have already seen.

Some investigators have used expressions indicating that they regarded the nerve-impulses as "purely physical." We see, however, that this view is not in agreement with our facts, for the fibre heated till it coagulates is still physical, but it will not now conduct impulses. Were these impulses entirely physical, the life or death of the fibre should not make the immense difference it does in conduction.

Everything points to neural conductivity being an expression of life, it is accelerated with heat, it is retarded with cold; and we know how vitality is exalted with warmth and depressed by cold. Then there is the action of poisons, narcotics depressing the conductivity just as they depress other manifestations of life.

But there is one difficulty about the vital view which ought to be mentioned: if the conduction of nerve-impulses is a vital process, we ought to find certain waste-products as the result of that activity. As long as there is life, there are waste-products (katabolites). The experimental difficulties in the way of demonstrating waste-products in medullated

nerves are very great, and were for a long time insurmountable. But the presence of carbonic acid gas has been inferred to be produced by active medullated nerve, while in active nerve-cells an acid, characteristic of vital action, has been seen, and the existence of increased heat-production has been demonstrated. From these and other facts, our only legitimate conclusion should be, not that waste-products do not exist, but that owing to the technical difficulties we have not yet been able to demonstrate them.

A difficulty closely bound up with that of demonstrating waste-products, is that of demonstrating fatigue in long active nerve-fibres. All living things, if made to work longer than a certain time, begin to show signs of functional incapacity, a condition we call fatigue. Fatigue, if disregarded, goes on to exhaustion. Now it is perfectly true that it is exceedingly difficult to show the existence of fatigue in nerve-fibres, they appear to be less fatigueable than any other living tissue. Brain and muscle are both much more easily fatigued than the connecting fibre. This is quite what we should expect; it would never do for the telegraph wire to become fatigued. It should be

ready at any moment, no matter how much it may have worked in the past, to convey messages from one instrument to another. The workers at each end may be tired out, the wires never. Something of this sort holds good in the nervous system. Nevertheless recent experiments, of too technical an order to be described here, have shown that some fatigue of medullated fibre can occur, but it is slight and not at all easily produced. It is otherwise with nerve-cells—the origins of nerves, for in them we have evidence, both chemical and microscopic, that fatigue can occur. Sleep, as we shall see later on, is the occasion for the repairing of this very fatigue. The possibility of fatigue is, then, to be expected in the neurone; and the general conclusion one comes to is, that although it is excessively difficult, really, to fatigue a nerve-fibre—under normal circumstances impossible—yet experimentally it may be done.

Can we now advance to any conception of the nature of the nerve-impulse in the light of the facts already before us? It is at least true that it is a state of activity propagated through the central living core of the fibre.

That the impulse is a condition of activity

is beyond a doubt. Something active must reach the muscle and fire it off to activity, and that something can start either in the nerve-cell, where the fibre begins, or at the spot of artificial (heterologous) stimulation. An excited or active state is, therefore, propagated from end to end of the fibre; but this wave of activity must mean, in ultimate analysis, agitation of the molecules of the neuraxone. States, then, of molecular agitation or vibrations in nerve-substance are propagated through the fibre. Evidently matter itself does not travel from one end of the fibre to the other, nothing material arrives at the lower end to enter the muscle bodily. But an excited state or wave so travels, and, on breaking on the muscle, stimulates it to contract. Since, however, we have evidence that nerve-impulses are associated with some amount of chemical activity, and since they *do* create electric current, it would be best to say that the nerve-impulse was a travelling state of physico-chemical excitement in the conducting core. It is, in short, *the* state which represents the specific activity of the nerve-fibre. All merely physical models are crude in illustration of this state of matters, but a simple scheme of the sort of thing may

be made with a row of marbles in a wooden groove.

If the marbles are all in contact, then a tap on number one sets the last running off, although none of the intervening marbles has moved from its place either absolutely or relatively. But the row of marbles has conducted an impulse of tapping from one end to the other of the line, and yet without any visible sign except the movement of the terminal marble. This is a rough but not misleading model of the propagation of the nerve-impulse.

The neuraxone in the centre of the fibre is, as we have seen, the outgrowth of a living cell, the nerve-cell (ganglion cell), and it is known to be very intimately related to the health and condition of its parent cell. In fact, the neuraxone is only an exceedingly long and slender process of the cell-body. We are, therefore, not surprised to know that if the cell-body be cut off, by any means whatever, from the neuraxone, the latter dies after a short time. Of course destruction of the cell itself results in the same thing—the death of the fibre. It does not matter how far away from the cell-body the severance occurs; the piece of fibre cut off from the

cell dies, the piece attached to the cell does not. It is customary to speak of the cell as "trophic" to or for the fibre, by which we mean that it is essential to the nutrition and life of the fibre. The fibre so cut off from its cell of origin breaks up chemically, the axis-cylinder becomes a row of granules (disintegrates), the fatty sheath breaks up into fatty globules, and is removed piecemeal by the leucocytes (phagocytes, see the volume on "Physiology," in this Library). This is called Wallerian degeneration, from its having been discovered by Dr. Augustus Waller (in 1850). Wallerian degeneration proves, amongst other things, that the nerve-fibre is a real, living thing, a part indeed of a living cell, so that no "purely physical" explanations about its activity will suffice. It must at once be apparent how useful the occurrence of Wallerian degeneration may be made in tracing the paths of neuraxones through the nerves and nervous system. Of course it is by the aid of the microscope that we trace the degenerated fibres, they do not take up dyes in the same way that normal fibres do.

Suppose we have destroyed certain cells in the grey matter or central nerve-cell portion of the spinal cord, then on killing the animal

some time afterwards and looking into the nerves, wherever we see degenerated fibres we know that they were originally connected with the cells previously destroyed. Their whole paths, marked out by fatty débris, could be traced from the cells of origin to the remotest depths of the tissues in which the nerves ended. In this way the most complicated nerve-paths may be unravelled by the microscope.

Although the portion of the fibre separated from the cell dies and is absorbed, the portion connected with the cell regenerates the lost fibre in due time. But if a nerve-cell itself is completely destroyed by any agency whatever, the cells near it do not multiply (subdivide) to make good the loss. Cells in many other parts of the body can do this, but the nerve-cells are so highly specialised that they have lost the power of reproduction. We start life with a certain number of nerve-cells, and if some are destroyed we cannot get any more.

We might, in conclusion, allude to the chemical constitution of nerves and the nervous system. Broadly speaking, the nervous system is made up of white matter or medullated fibres and grey matter or nerve-cells. In both fibres and cells, fatty substances are

found, but it is not fat in the ordinary sense. Ordinary fat has only carbon, hydrogen and oxygen, but the fat of the nervous system has in addition to these elements phosphorus and nitrogen. It is a complex fat associated with other substances of rather complicated chemical structure (the lipoids). Since the fat of the nervous system contains nitrogen and phosphorus, and since the true fats and sugars contain neither, the nervous system must be built up from food which contains both these elements, that is, the flesh foods. The important point in a dietary is that more than one type of food-stuff is needed to build up the highly complicated substances (lecithin and cholesterin) without which the nervous system cannot be constituted. As we shall see later on, many forms of nervousness are due to starvation of the nervous system.

CHAPTER III

CENTRES AND REFLEX ACTION

WE cannot advance very far into the subject of nervous activity without encountering the notion of a nerve-centre.

A nerve-centre is a collection of nerve-cells set apart for superintending, looking after, having to do with a particular function or activity of body. Thus we have a collection of nerve-cells which attends to the movements of breathing; the cells emit impulses in a rhythmic fashion which cause the diaphragm and other muscles of breathing to contract and relax some eighteen to twenty times in the minute. We rightly call this the breathing or respiratory centre; if destroyed, breathing stops; if it is stimulated, breathing gets faster or deeper, or both. It is the centre suddenly destroyed in hanging, when the weight of the body causes rupture of the Medulla Oblongata where the centre is.

The breathing centre was one of the earliest

known ; a French physiologist Flourens (born 1794, died 1867) did the classical work on it about 1822. Now a centre cannot be an isolated or unrelated thing either structurally or functionally.

Just as in the telephone exchange there must be wires coming in, else no proper messages could go out, so nerves must run into centres in order to convey to them messages as regards the states of the tissues the activity of which the centres control.

We all know very well how the breathing centre can be made to emit gasps by a douche of cold water on the skin, or made to hurry as in the case of a dog on a hot day. Now the skin has nothing to do in itself or directly with the breathing, but from it nerve-fibres run —no doubt by long paths—up to the breathing centre ; and when cold water is dashed on the head, the breathing centre is stimulated and it therefore puts forth more vigorous impulses of an inspiratory kind, the muscles of inspiration act violently and air is gaspingly drawn in.

It should be noticed that this gasping is not voluntary ; it goes on outside the sphere of the will. The douche on the skin is used to arouse the first breath of the new-born

child who may happen not to breathe spontaneously.

The centre which we have selected is one which is said to work in an automatic manner, by which we really mean that it works rhythmically and without obvious dependence on currents coming into it. In a later chapter we shall study rhythm a little more in detail, but it would be a mistake to suppose that there are no incoming currents intermittently affecting the respiratory centre. Currents are intermittently ascending certain nerves from the lungs which have a very great deal to do with the particular rhythm of the movements of breathing. When these nerves are cut, the respiratory centres—for there are two, one on each side of the mid-line—assume an exceedingly slow rhythm of very deep breaths.

Take an analogy; a boy has been told to sit on a fence and shout at crows so many times a minute; unless you keep constantly visiting him and stirring him to action, he tends to do nothing except to give an occasional shout at long intervals. The breathing centre, although able to work of itself, is hurried up, as it were, by impulses rhythmically ascending from the lungs; but it can

also be influenced by impulses from the skin and from the internal organs as well as from the brain. When we dash cold water on the skin we hurry up the breathing centre by afferent skin-currents; when there is pain in the internal organs, the breathing centres are affected by currents of internal origin; and finally when we elect to breathe faster than usual, we are voluntarily influencing the respiratory centre. What happens to the respiratory centre we are here taking as typical of what may happen to any centre, namely, it may be influenced by currents (impulses) from the surface of the body or from the interior or from the realms of consciousness. In other words, a centre is capable of being stimulated or roused to action greater than it was exhibiting at the moment the stimulus arrived; the boy shouts louder and louder at the crows in proportion as he is urged to do so.

But a centre can not only be roused to additional activity, it can be depressed or repressed in its activity. The technical term for this diminution of the activity of a centre is "Inhibition," a term we shall have to use over and over again in the following pages. It means that a function is depressed or

restrained in its intensity without permanent damage being done to the underlying structure itself. For, of course, a function can be depressed through damage being done to it, whether that damage be by physical or by chemical means. Thus, as regards the breathing-centre, it can be depressed by poisons circulating in the blood. This is not true inhibition, it is called blood-poisoning or toxæmia ; the cells of the centre are depressed by chemical substances in the circulating blood, and the breathing is in consequence slower. We know the disagreeable sensations when our nerve-centres are poisoned with the products of indigestion, we have headache, sickness, sleepiness and malaise.

True inhibition is restraint of a function without any damaging effect. To take an analogy ; suppose we tell a boy to sit and hold in a dog by a leash to prevent it running away ; then the boy is a " centre " for holding in that dog, and it is clear that he can be either stimulated or inhibited as regards this duty of his. We have already seen the sort of thing that would happen if we stimulated him, he would pull the dog in all the more ; but now if we inhibit him, exactly the opposite will happen, he will pull in

the dog less effectively and it may escape altogether.

Now inhibiting the boy is not the same thing as injuring him; no doubt if the boy were rendered unconscious by a blow on the head, he would let the dog escape, that would be depression of the centre by physical damage; or again, if the boy were rendered insensible by a poison (chloroform, for instance) the dog would also escape, but neither would that be inhibition. The boy would be inhibited within physiological limits if you went up to him and engaged his attention by asking him to do some mental arithmetic; the better he did his calculation the more loosely would he hold the dog in; you would have inhibited the intensity of his activity, which is to hold the dog in. After inhibition, the boy would be as fit to hold the dog in as he was before you spoke to him, but that would not be so if he had suffered physical or chemical damage. "Do not speak to the man at the wheel" is, in physiological language, Do not inhibit the brain-centres of the steersman; in psychological language, of course, it is, Do not engage his attention. Nerve-impulses are descending from his brain-centres to the muscles he uses in steering the ship,

in proportion as his nerve-energy is deflected into other channels (centres for hearing), there will be less energy for the muscles used in the act of steering. Not only will there be less energy for them but the whole complicated act of steering will be less perfectly performed, the muscles may act less accurately together, in a manner called un-coordinated. A centre is, then, a collection of nerve-cells with a certain power of activity which may be called normal, and the intensity of this activity can be either raised or depressed. Anything that alters or tends to alter the intensity of the activity is called a stimulus, and those stimuli which exalt the activity may be called positive, those which depress it negative. As a rule, when one speaks of a stimulus or stimulation, one is thinking only of the stimulation of the positive order. Now stimuli tending to exalt activity may act for too long a time, and produce functional incapacity or exhaustion; the centre is then said to be overstimulated; as an example of this we can take the deafness of boiler-makers, men who have to work for hours in the terrific noise of the hammering of iron plates. The excessive and long continued stimulation of their centres for hearing results in the ex-

haustion of the cells of the centres, and the effect in consciousness is deafness. Over-stimulation of a motor centre results in the inability for any further action, a condition known as collapse or "shock." Conversely, inhibition can pass over into a state of too long continued depression which may be injurious.

Although it is proper to distinguish, theoretically, true physiological inhibition from damaging depression, it is so very difficult to do so in any given case that we cannot always practically manage it. Thus, chloroform is not so much an inhibitant as a poison to the nervous system, yet it would be pedantic to refuse to speak of the inhibitory effects of a dose of chloroform even although we are certain that an overdose will certainly bring about chemical damage to the nerve-cells which may not be repaired for some considerable time. Chloroform depresses activity and abolishes consciousness, and that is usually alluded to as inhibition.

The notion of a centre we are at present considering is a purely functional one, that is, not merely the notion of a group of nerve-cells giving rise to fibres, but a group of nerve-cells devoted to the superintendence of a particular activity. This difference is very

well illustrated in the case of the nerve-cells giving origin to the nerves which innervate the diaphragm, one for each half of it (the phrenic nerves). These cells of the phrenic nerves are, according to anatomists, the "nuclei" of these nerves, but though they send nerves to the diaphragm they do not form a respiratory centre.

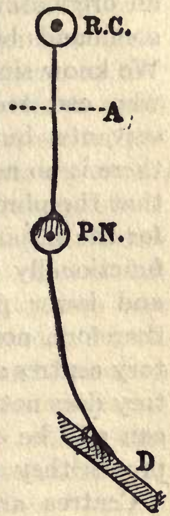

FIG. III.—R.C. is the respiratory centre. D is the diaphragm. P.N. is the phrenic nucleus. A is the place of a section.

For if the nerve-fibres running between the respiratory centre (R.C. in Fig. III.) and the phrenic "nucleus" be cut across, say at A, the diaphragm stops acting, which means that the phrenic "nucleus" has ceased to send any more impulses to it. But the respiratory centre has not ceased to send out impulses, as the physiologists can prove in several ways. The cells of P.N. (Fig. III.), are still intact, but severed from the higher cells of R.C., they are unable to send out respiratory impulses on their own account. They form a centre in the anatomical sense

but not in the physiological, for they cannot act of themselves and keep up the breathing rhythm proper to the animal in question. They belong functionally to a lower order of nerve-cell, a distributing centre only, not an originating one, cells capable of receiving commands but incapable of originating them. We know similar cases in individuals, persons who can receive and execute orders, good servants, but bad or incompetent masters; there is no neural socialism. It is not merely that the phrenic nuclei do not act vicariously for the respiratory centre, they *cannot* do so; functionally they are on a wholly different and lower plane. The phrenic nuclei are, therefore, not really even subsidiary respiratory centres: but severance from the respiratory does not paralyse them, for reflex actions can still be carried on through them, which proves they are still functionally capable.

Centres are, of course, not only executive; we have centres for the reception of impulses, whether these arouse consciousness or not. Thus we have centres for seeing, hearing, touching, smelling, tasting, and so on. These sensory centres are highly specialised portions of the brain in which impulses from the end-organs of sense are received and are

usually worked up in consciousness into the perception of an object, a sound, a thing in contact with the skin, a smell or a taste. These centres are specialised to receive, as the others are specialised to emit. But it is quite clear that no centre can receive and never transmit, just as no centre can emit and never receive. A sensory centre, in the first instance, receives and may for a time retain, but sooner or later it transmits impulses either to an executive centre or to another sensory centre. Thus when I see an apple, impulses not only pass to the centre for vision, but onwards to the centre for taste, and from both of these, impulses can go over to the motor cells in the middle part of the cerebrum, whence volitional impulses descend to the muscles of the hand prepared to seize the fruit. (See Fig. A.) That this is the physical basis for the association of ideas, there is little doubt.

The speech centre is a good example of one that receives and then transmits. We learned to speak because we first heard words and then educated a special sensory centre for the hearing of words; then we sent out messages to the muscles of articulation to pronounce words. But children who are deaf are also

dumb (deaf-mutes), because although their speech centre can emit, it has never had an opportunity to receive; having received nothing, it can emit nothing. There is an account given of a naval officer who, in the act of giving an order, received an injury to his head which necessitated his being removed to hospital. The command was unfinished at the moment of the accident; when he was convalescent he suddenly sat up and finished the words of the command.

As regards its structural units, the central nervous system is built up on the reflex nerve-arc, and functionally on the reflex action. It is not too much to say that, with exception of acts which are the result of the power of the will, the reflex action enters into nearly every other neural act. A reflex action is best described on its functional side first, and as a type we shall first take a lowly or primitive sort. The exact meaning of "lowly" in this connection will be made clearer later on.

A reflex action is (1) one in which consciousness does not need to be aroused in order that the action be carried out; (2) one in which the will has nothing to do with starting the action; and (3) one in which the will

cannot arrest or restrain the action. Our visits to the dentist will supply us with an example of what is meant. We remember how the saliva would keep collecting so long as the dentist touched the teeth or lips or gums with one of his many forms of metal instrument. Now we have not willed this outpouring of saliva, and we could not by our most energetic volition stop it, or even lessen it, much as we and the dentist would wish that to be done. We clearly recognise that so long as the instruments keep touching the mouth, the saliva will flow; *we* in a sense have nothing to do with it. It happens; we do not cause it to happen, it is a reflex or involuntary action. We are aware of the contact of the metal on the gum, and when the saliva happens to overflow we are aware of its wetness on the skin, but of the process of the secretion and flow of saliva we are totally unconscious. The secretion would proceed just the same in an unconscious person; it is not the sensation of contact of the instrument with the teeth that has produced the flow, it is the irritations of the afferent nerves from the teeth which have excited the centre for the secretion of saliva, a centre quite outside voluntary control. This flow

of saliva is not *behaviour* in the true sense of that term.

Now on the side of structure, this reflex action requires under the simplest conditions, only two neurones—an afferent commencing at the periphery and ending in the central nervous system, and an efferent commencing in the central nervous system and ending at the periphery. In the simplest possible reflex, the termination of the afferent neurone is upon the cell of origin of the efferent, the afferent fibre ending in a brush (arborescence) upon the cell which is trophic for the efferent neurone; this clasping of the beginning of the one by the end of the other being called a synapsis (C in Fig. I.). All that is really needed for a reflex action is, then, a receiving neurone and an emitting neurone, though usually in actual fact a third or internuncial neurone is interpolated between the other two. Impulses originated in the skin or teeth or anywhere at the periphery, in the muscles or in the internal organs, travel inwards towards the central nervous system, and there they seem to be turned back or reflected to the periphery again. You tickle the toes, and the muscles of the feet twitch; it is as though the impulses set up in the skin ran up

to the spinal cord and were there reflected back to the muscles of the place they started from; this is why such involuntary actions are called reflex. The analogy of reflection of light was before the early thinkers on the problems presented by the central nervous system and its behaviour as expressed through its nerves.

The term or notion of reflex action in neurology originated with the well-known English anatomist, Thomas Willis (b. 1621, d. 1675), a pupil of the great William Harvey, who wrote thus: "We may admit that the impression of an object driving the animal spirits inwards . . . gives rise to sensation, and that the same animal spirits rebound from within outwards in a reflected way and, as it were, call forth movements." Later work showed that the presence of sensation was not essential to a reflex action. Descartes in 1649 had quite clear notions of reflex action, and adopted the analogy of reflection of light.

Just as a boy playing fives, knocks the ball against the wall and expects it to bound back at the same angle at which it struck, or the billiard player expects the ball to return from the cushion at the angle at which he sent it,

so the nerve-impulses seem to be turned back or reflected in the centres of the central nervous system.

The afferent neurone and the efferent neurone with the synapsis between them are known as the "reflex nerve-arc," a term originated by the English physician and man of science, Marshall Hall (b. 1790, d. 1857). The reflex centre is, in the case of only two neurones implicated, the cell of origin of the efferent neurone; in the case of an internuncial neurone, the centre is the internuncial neurone plus the cell of origin of the efferent neurone, the former being a one-celled centre, the latter a two-celled centre.

Now it should be remarked that the idea of an angle between the direction of the incoming impulses and that of the outgoing, is not actually necessary, physiologically, in order to constitute a reflex action. The receiving neurone and the emitting neurone need not really make an angle between them, they might be in the same straight line. All that is needed for a reflex action on the structural side is a receiving and emitting neurone connected through a centre; all on the functional side is an action not necessarily involving consciousness and not due

to any activity of the will. What constitutes a reflex action is that impulses originated at the surface of the body or in any of its organs, produce, through an appropriate centre, a particular kind of activity, and that independently of the instigation of the will—the "involuntary" action of the older writers.

Let us take a few additional instances of reflex actions in the intact human being before we examine them under experimental conditions in the lower animals. When an intoxicated man swallows the tube of the stomach-pump which is pulled down by the muscles of his throat into his stomach, a reflex action is going on; for he is unconscious, he is not exercising his will, *he* is not performing any kind of action, a reflex action is being performed. In consequence of his previous behaviour he is not now exhibiting any behaviour; *he* is not swallowing the tube, it is being swallowed—if not by him, then in him. In our own sober senses we know that when anything swallowed passes a certain point, it is "beyond recall." Or again, we get some grit into our eyes, and in consequence there is a great outpouring of tears. *We* are not weeping, there is no emotion calling forth tears idle or otherwise, and we have certainly

not willed tears to flow. The lachrymal glands have been reflexly stimulated to secrete. The stimulation at the periphery of the sensory nerves of the cornea, has set up impulses which have travelled to some centre for lachrymation and roused it to activity in such a way that it has sent down secreto-motor impulses to the lachrymal glands. Clearly there must be accessible to incoming stimulation some specialised portion of the central nervous system which is set apart for inducing secretion in the tear glands, just as we saw there was a similar region for the salivary glands. Such a specialised portion of the grey matter of the central nervous system is a centre, in this case a reflex centre.

On the functional side, the element of inevitableness is one very characteristic of reflex actions. Every time teeth are irritated saliva flows; every time grit gets into the eye tears flow; every time a dog sees or smells food, if it is hungry, gastric juice flows, and so on. Inevitableness is characteristic of a large number of reflex actions; and it is that unvarying, mechanical uniformity of the response which distinguishes these from voluntary actions.

The element of personality does not enter into them, they do not constitute behaviour, they are outside the sphere of psychology. A study of these simple reflex actions, flow of saliva, of tears, shows us what is meant by innervation. The salivary glands and the tear glands must be innervated, that is, possess the property of receiving nerve-impulses or how else could irritation of the teeth or eye arouse glands to activity? The teeth and the glands are not directly connected. The saliva and the tears flow because the teeth and the eyes are connected with the nervous system, which in turn is connected with the respective glands. The glands are innervated, and are receiving nerve-impulses all the time. This normal, constant innervation of salivary glands just keeps the mouth wet and that of the tear-glands just keeps the surface of the eye-ball moist, but in a moment a positive stimulus can arouse the centre for salivation to activity and cause a copious flow of saliva, or a negative stimulus can inhibit the centre and dry up the mouth altogether. Similarly a positive stimulus to the centre for lachrymation can call forth a copious flow of tears, while a negative one can dry up the fountains of the eyes altogether.

"Home they brought her warrior dead,
She nor swooned nor uttered cry,
All her maidens, watching, said—
'She must weep or she will die!'"

The strong emotion had inhibited her centre for lachrymation. The normal constant state of the centre maintains in the glands what we may call normal chemical tone, and this tone can be raised or depressed by a positive or a negative stimulus respectively.

We have every reason to believe that large numbers of phenomena in the lower animals are of the nature of pure reflex actions. The changes of colour in the skin of animals of the frog tribe, the chameleon, or of certain prawns has been proved to be due to the action of light falling on the eyes. It has been demonstrated that if the eyes are cut out, or even hooded, the changes characteristic of the animals when exposed to light do not occur. Similarly there are no skin changes if the nerves from the eyes to the nervous system be cut. We must, therefore, look on these changes of skin-colour in the frog (light in light surroundings, dark in dark) as true reflex actions, the ingoing part of the nerve-arc being the nerve from the eye, the outgoing being certain neurones innerva-

ting the pigment—containing cells in the skin (chromatophores). The frog's consciousness has nothing to do with the results in the skin of exposure to light, for exactly the same things happen if the frog has had its brain (cerebrum) previously destroyed. The frog cannot be a light or a dark frog at will, it has to become whichever is reflexly decreed. Neither the Ethiopian nor the frog can change his skin, that is, not voluntarily. The chameleon is not to be blamed for assimilating himself to the colour of his surroundings; *he* does not do it, it is not behaviour, it is involuntary or reflex action; it is done in spite of him, as it were, by the reflex activity of his nerve-centres. A very large number of reflex actions are carried out through segments of the spinal cord, so that even in animals in which the brain has been destroyed (decerebrate animals) many typical reflex actions can be elicited. The classical demonstration experiment on reflex action is, indeed, on such a preparation; one destroys the brain by "pithing" the frog, that is, passing a blunt instrument into the inside of the skull, so that all its sensation is abolished and its volition too. Decapitation will do just as well, but in that case there is an unnecessary loss of

blood. If now, when shock has passed off, the insensible frog be suspended by a hook through its jaw, it will hang down vertical and remain motionless exactly like a dead frog, or one the whole of whose central nervous system has been pithed. The decerebrate frog is, however, far from dead; its heart beats, it breathes, and if given food it will live for a long time. But hanging there by the hook, it never makes a single spontaneous movement, unless stimulated it would hang there until dried up. This is because its brain has been removed, the centres for sensation and willing have been destroyed. As it does not feel the hook through its jaw, and has no desire or will-power to move a muscle, it never changes its position. If, however, you place a piece of blotting-paper, soaked with weak acid, on one of its flanks, you will find that, after a short interval, the hind leg of that side is brought up swiftly and with accuracy to sweep away the irritant. This action you can cause to be repeated again and again, it will be performed with mechanical inevitableness each time. Of course one must take certain precautions, such as washing the acid off each time so as to prevent the irritations getting greater and greater, waiting

long enough to prevent fatigue of the centres, always using the same strength of acid, and so on, but, these things being attended to, the reflex action can be elicited with unfailing regularity. Here there is no question of consciousness possibly originating or interfering with the result, for the seat of consciousness is gone from that frog for ever. Later we may look into the point in greater detail, but we may here say that all evidence goes to show that there is no consciousness whatever in the spinal cord.

This preliminary study of reflex action has, then, given us some clearer insight into what a centre is. A centre is a group of nerve-cells so constituted that when these cells are stimulated in any way whatever, only one kind of activity, some special activity, is the result. A discharging centre is *for* an action, it presides over it, when stimulated that action occurs more intensely, when inhibited that action is restrained or suppressed. When the centre is destroyed, the action is rendered impossible. The doctrine of centres affirms that there is specialisation throughout the nervous system, that certain cells and these alone are concerned with the performance of a particular function, that if that group be

destroyed some particular activity becomes impossible. If this functional specialisation did not exist, then any one cell-group in the central nervous system could act vicariously for another, but this does not happen. The respiratory centre cannot act for the sweating centre, nor either for the vomiting centre. Just as a gland is not a muscle and cannot do a muscle's work, so the centre for salivation is not that for the flow of tears and cannot do its work. There is, in fact, higher specialisation in the nervous system than elsewhere. One neural region governs the muscles of breathing, another the diameter of arteries, another the glands of perspiration, another those of gastric juice, another the act of vomiting, while others still are the places of the uprising of emotions, volitions, speech or memory. Under existing physiological conditions, the centre for smell, for instance, cannot act vicariously for the centre for touch, the speech centre cannot take on the duties of the writing centre, the functional capabilities of the centres are as strictly limited as they are highly specialised. The central nervous system is not a neural chaos in which the units are unrelated or equivalent existences, but it is a cosmos in

which the functional units are differently endowed and are related to each other after the manner of a hierarchy, the centres being arranged on several functional planes. Centres are co-ordinated by being subordinated some to others. There is no equality of functional position as there is no equality of capabilities. The nervous system knows no such thing as socialism, if by that is meant equality of position and powers. But in the nervous system there is a neural society in which there are aristocrats who rule and give orders, and servants who serve and obey. Higher centres control but do not domineer over lower. The doctrine of a neural hierarchy is one of the most luminous in modern neurology. For we cannot agree with certain writers who hold that the doctrine of centres is a personification and an unwarrantable metaphor, a piece of neurological anthropomorphism.

This is perhaps the place to mention some recent most interesting experiments on what is called nerve-crossing. For instance, the nerve that inhibits the heart was cut through and made to grow into the nerve that dilates the pupil. This new artificial nerve, beginning in the centre for restraining the heart and

ending in the iris, on being stimulated actually dilated the pupil. This proves that the nerve-impulses, when once they are travelling in the nerves, are not specific, that is, that their character depends on the nature of the tissue or organ in which they end. This is sufficiently curious, but it is still more curious to know that the new nerve can actually also maintain the tone of certain blood-vessels of the ear and head, that is, impulses starting as cardio-inhibitory may be *expressed* as vaso-motor. These experiments demonstrate what is called the non-specificity of nerve-impulses.

CHAPTER IV

THE VARIETIES OF REFLEX ACTIONS

In the last chapter we got some idea of what a nerve-centre is, and the part it plays in reflex action: we may now go on to survey the whole field of reflex actions and try to discriminate between their various kinds. The most primitive—inevitable—reflex actions are those known as "excito-motor," or those in which consciousness does not participate at all. They are seen most typically in the activities of decerebrate animals ("spinal animals"), and in human beings who have been unfortunate enough to have the spinal cord severed, say, in the middle of the back. The "spinal animal" is one in which the brain-stem has been severed just above the respiratory centre, so that it breathes and its heart beats, but it has no consciousness.

A typical excito-motor reflex is that seen in the decapitated snake, which, when a red hot poker is brought near it, winds itself

round it until it is scorched to death. Certainly it would not do this voluntarily. Nor can we suppose would the moth of its own free will rush into the flame until consumed; it seems rather the result of a reflex action, the unavoidable response of its muscles to the stimulus of light. When a man has his back broken, his brain can no longer move his legs, nor can he have any sensations in his legs or trunk; yet his muscles can be made to contract reflexly.

Now, as we have already seen, excito-motor reflex actions may involve very different organs, but practically they can be all included in the following four groups:—Excito-muscular, excito-vascular, excito-glandular, and excito-metabolic.

By excito-muscular we mean that muscles of some sort express the reflex action, by excito-vascular that heart or blood-vessels do so, by excito-glandular that glands do so, and by excito-metabolic that some change in the nutrition of tissues is the expression of the reflex process. Before we take examples of these sub-classes, we should remember that a reflex action may be the result of either the exaltation or the depression of the excitability of the centre "for" it.

When a reflex action is the outcome of the exaltation of the activity of a centre, we call it a positive reflex, when the result of the depression of the centre, a negative one.

As examples of excito-muscular reflex actions we have all those muscular contractions in decapitated or spinal animals as the result of the stimulation of any kind of afferent nerve; convulsions in children as the result of "teething" or of the presence of intestinal worms; contraction of the iris when light falls on the retina, the part of the brain-stem containing the centre for this being divided both from the brain in front and the spinal cord behind. Muscular movements during sleep, as the result of tickling the skin, or of any other form of irritation which does not awake the sleeper, are excito-muscular. The last stage of swallowing is an excito-muscular reflex, so is hiccough from irritation in the stomach. As examples of excito-vascular reflex actions, we have morbid flushings and interferences with the heart's action due to certain irritations, the result of indigestion or other morbid states of internal organs. As examples of excito-glandular reflexes we have the outpouring of gastric juice as the result of chewing and swallowing of food.

Excito-metabolic reflexes are such as we spoke of when describing the change of colour of the skin of frogs, or the outer surface of prawns, as the result of light-stimulus.

In such reflexes as excito-motor we should note that each segment of the spinal cord can be isolated from all others, and yet the reflexes through it remain intact. As has been well said, "the spinal animal is no longer an individual but a series of living segments." The decapitated body of a centipede may be bent into several different curves by bringing ammonia vapour into contact with as many different spots of its surface, the reflex response of each segment being to bend away from the irritating vapour.

The next higher group of reflex actions is that known as sensori-motor. By "higher" we mean here, involving sensation which is psychologically higher than the previous group. Here sensation is aroused, but it is not of the cause or essence of the reflex action; the sensation is, as it were, a by-product from the reflex action proper. There are again to be distinguished four sub-groups: sensori-muscular, sensori-vascular, sensori-glandular, sensori-metabolic.

The structural reason for the concomitant

sensation is that the afferent neurone carrying in the impulses in these cases bifurcates in the spinal cord or brain-stem, and proceeds more or less directly to the regions of consciousness in the brain itself (see D in Fig. I.). These reflexes are not strictly within the purview of psychology; their occurrence does not constitute behaviour; consciousness is aroused, but it is not needed. As might be expected, this group is a very large one, as the following examples will show:—

Sensori-muscular; coughing, sneezing, winking from a foreign body under the eye-lids, laughter and spasms from being tickled, the taking of a deep breath when cold water is dashed on the skin. Now each of these may be voluntarily imitated. We can cough or sneeze or wink or laugh, or take a deep breath intentionally; but true coughing or sneezing is a reflex action. A cough that is the result of some irresistibly tickling sensation in the chest or elsewhere is a reflex action. "Love and a cough cannot be hid," is an old Italian proverb, and it alludes to the imperativeness of a reflexly produced cough. Coughing in bronchitis—irritation in the bronchial tubes—is a pure sensori-muscular reflex action, the ingoing paths begin in the lungs and end

in the respiratory centre, the outgoing begin in the centre and end in the muscles of breathing. That coughing is reflex is shown by the fact that however much we want to stop it, we cannot. Many people who cough in church would give a good deal to be able to restrain the cough, but are quite unable, the muscular mechanisms must be active because their centres are excited by strong incoming impulses (reflexigenous). Similarly with sneezing ; a tickling in the nose, a bright light, a draught of cold air to the skin may all produce a pure sensori-muscular reflex action. That is to say, afferent nerves from nose, retina or skin may all separately induce the reflex expression ; this is called " using the common path " ; the same efferent neurone receives impulses from very different afferent ones. Again, such a reflex action as sneezing cannot be voluntarily stopped (inhibited) ; some people would be only too glad to know how to suppress a sneeze imminent at an awkward moment, the peroration of a funeral oration, or of some tragedian's speech. Pressing hard on the upper lip will sometimes suppress for a time a very urgent sneeze. We shall analyse this state of things in a later chapter.

When a door bangs and you jump in-

voluntarily, that is a reflex action. When Charles Darwin gazed at the cobra in the Zoological Gardens, and, trying hard not to blink when it struck out at him, nevertheless had to blink, he was exhibiting sensori-muscular reflex actions. He was trying not to blink, and yet he could not restrain this inevitable reflex. The contraction of the iris in a bright light is an excellent example of a sensory-muscular action carried out through a centre in the upper part of the brain-stem. If this region be severed from all above and below it, the closing in of the iris, when light falls on the retina, takes place all the same. This illustrates the local or segmental position of certain reflex centres: so long as the segment containing the centre is intact, so long can the reflex action be carried out. This iris reflex does excellently as a typical example of a reflex action; it can be carried out in unconsciousness, for instance, during the earlier stages of chloroform anæsthesia. The will can neither start it nor restrain it. We are unconscious of anything about it, except the presence of the light. If the afferent nerve—the optic—be severed, light falling on the retina produces no closing of the iris, if the efferent nerve be cut, though all else

is intact, the light produces no result. If the centre be destroyed, although both the nerves are intact, no reflex action occurs. If the retina be removed, and light made to fall on the optic nerve directly, nothing happens, because the nerve itself cannot respond to light but only to impulses generated in the retina by the action of light there. Electrical irritation of the optic nerve, however, or mechanical irritation (pinching, crushing), will cause impulses to ascend the reflex nerve-arc and the iris will respond.

As examples of the sensori-vascular reflexes, we have such occurrences as the skin becoming pale on our going out into the cold air, or flushed on remaining in a warm room. In the former case, the cold air acts as a stimulus to certain afferent nerves going to the centre for keeping blood-vessels contracted, the impulses so generated raise the activity of the centre, and it emits impulses more strongly tending to close the vessels; in the latter case, the hot air acts precisely in an opposite way, the centre is restrained from sending such vigorous impulses as before. Impulses that tend to close blood-vessels are called vaso-constrictor. The glow produced by sitting in a hot bath is an example

of a (negative) sensori-vascular reflex action. It is well known that listening to music causes the small blood-vessels to be closed down, and the pressure of the blood therefore raised behind them. This is not brought about by the will, nor can it be prevented thereby, it is a (positive) sensori-vascular reflex. When martial music makes the heart beat faster we have a positive sensori-vascular reflex going on; when sad music slows the heart, we have the negative variety of the same reflex. The increased tone of the heart due to one's sitting in a bath of äerated water (Nauheim treatment) is a sensori-vascular reflex action (sensori-cardiac), the continual bombardment of the skin by the bubbles of gas acts as the afferent stimulation, and the outgoing impulses descend to the heart and cause its tone to be increased to a notable degree.

The sensori-glandular group of reflex actions is a familiar one. We all know that something acid or sour in the mouth makes the saliva flow, and we have seen that irritation of the teeth or gums has the same effect. The saliva flows reflexly. Similarly, when a bright light in the eye or grit under the eye-lid causes the tear-glands to secrete, we have

an illustration of sensori-glandular reflex actions.

The sensori-metabolic reflex action is, perhaps, not so easily recognised as some of those we have been alluding to, but there is no doubt that such a group exists. It is possible that the bronzing of the skin and ultimately the blackening of it in the negro, as a response to the light and heat of the tropics, is a reflex affair. If so, it is akin to the excito-metabolic changes of pigmentation in the frogs and prawns; but it may be the direct response of the living cells to light. In fact, the point needs further enquiry. All tissues, however, are influenced for good by sensory stimulation. It is well known that light improves the tone of tissues, that bright surroundings improve the health, and that dull surroundings have an opposite tendency. We shall look into this more fully when discussing the innervation of tissue-tone, but an example of the sort of thing may be quoted here. It is now known that the quality of the milk given by cows kept in well-lighted byres is noticeably better than that secreted by animals kept in dark cow-houses. This means that under the former conditions, the cells of the mammary glands have had

their chemical tone raised as compared with the cells of the cows kept in comparative darkness. But, clearly, this maintenance of good tone in such a gland as the mammary, itself far away from the direct influence of light, must be a reflex action in which the falling of light into the eye acts as the source of afferent impulses. Fowls are in better health in well-lighted than in feebly lighted hen-houses. The stimulating influence of bright surroundings is thoroughly recognised by people in general who feel themselves brighter and better for a change of scene, a change from grey skies to blue, from sunlessness to sunshine. But the good effect is reflex; those who benefit by it do not will it. They will to take a holiday, but unknown to them, sensori-metabolic reflexes do the rest. Similar facts are fully recognised by those in charge of the insane, they know how beneficial it is for their patients to be surrounded by bright, tonic influences. These influences act reflexly.

Very closely allied to sensori-motor reflex actions, are those due to the existence of pain, the learned name for which is algio-motor (from *algos*, the Greek for pain). The pain-produced reflexes we may subdivide just as

we classified other varieties, namely, algio-muscular, algio-vascular, algio-glandular, and algio-metabolic. Of course, pain is simply a disagreeable variety of sensation, that is, on its mental side; but the severe irritation or damage done to the tissues gives rise to the effects which we may call algio-motor.

As examples of algio-muscular reflex actions, we have, in body-muscles, their writhing and contortions from severe pain anywhere, also vomiting from the various colics due to spasms of one internal organ or another. The intense irritation, for instance, produced when a stone (calculus) is trying to force its way down a narrow tube (the result of which is, in consciousness, pain), is the cause of intense impulses which find their way into the vomiting centre. This pain-vomiting is of considerable importance to the physician and surgeon in connection with the localisation of disease. As examples of algio-vascular reflexes, we have the well-known case of the stopping of the heart through great pain, such as used to occur in surgical operations before the introduction of chloroform; and the blushing or blanching from agony. These latter are negative and positive reflexes respectively. The algio-glandular reflexes are equally well marked.

The profuse perspiration as a result of pain is a pure reflex action of the secretory type. The salivary glands in animals are easily roused to activity by accidental, painful stimulation of sensory nerves.

The algio-metabolic group is not indeed clearly distinguishable from the sensory-metabolic. Over the areas of painful nerves the hair is sometimes whitened or it comes out; it is quite possible that these changes, due to serious interference with the nutrition of the part, are the result of reflex actions inseparably bound up with the existence of pain. The sheaths of large nerves are provided with nerves (nervi nervorum), and as far as we can judge, these nerves of nerves transmit only painful impulses, as in the various neuralgias.

When we reach the reflexes produced by emotions, we enter the sphere of things mental, the study of which is outside our present enquiry. Only on one side, however, do the emotio-motor reflexes belong to psychology. Their effects in muscle, heart or blood-vessels, glands or other tissues are what concern our present study. To illustrate the kind of thing we are considering, take the case of emotional blushing. The centre for this is,

of course, the centre for the blood-vessels, the vaso-motor centre in the medulla oblongata; but while a negative sensori-motor reflex action through that centre results in flushing, an emotio-motor reflex through the same centre is called blushing. In the former case—flushing—the sensory impulses may have arisen in the skin from a hot bath or a poultice; in the latter case—blushing—the impulses, afferent towards the vaso-motor centre, have descended from the cerebrum. As regards the centre, it makes no difference whether the currents coming into it originated at the periphery or in the brain; they inhibit it, cause a negative reflex action through it, as the result of which the vessels have their calibre opened out: but the existence of an angle at the centre, is, as we have seen, without any significance. Impulses descending into the vaso-motor centre influence it as really as though they had ascended to it. The emotional impulses come from certain regions of excited brain—the seat of disturbance, which, on its mental side, is called the emotion.

As before, we subdivide into emotio-muscular, emotio-vascular, emotio-glandular and emotio-metabolic. Trembling from joy,

rage or fear is an emotio-muscular reflex action; it is absolutely involuntary, it cannot be controlled by the will. Fear or apprehension dilates the pupil, another example of an emotio-muscular reflex action. Emotional states, as is very well known, can influence the digestive organs, in this instance their muscular coats, either in the direction of augmenting or of quelling their activity. The alterations of the respiratory rhythm, from sighing for instance, are emotio-muscular reflexes.

When we come to the vascular reflexes, we come to what are perhaps the most familiar of all reflex actions. The violent action of the heart under the influence of emotion is quite notorious. So susceptible is the heart reflexly to the influence of some of the "softer" emotions, that the word "heart" has come to be a synonym for the emotions themselves. Emotional states may either greatly accelerate the rate and augment the force of the heart's action, as in states of joy and excitement; or they may depress and slow the heart, and, in extreme cases, stop it altogether. Thus, certain violent emotions can totally inhibit the heart, both great joy and great grief being equally potent. This is an emotio-motor

reflex cardiac inhibition; the person may die from the heart's stopping in this way (emotional syncope). Hence, we have to be careful not to cause certain persons with feeble hearts to be told, especially suddenly, very good or very bad news, as for instance, by telegram. Cases are by no means uncommon of sudden death brought about by such means.

Blushing as a sign of the emotion of shame or modesty is very well known to be outside the sphere of the will. It cannot be dispelled voluntarily, and it certainly cannot be induced voluntarily.

Actresses have been known to weep voluntarily, but never to blush in that manner. Darwin quotes Seneca's remark, "That the Roman players hang down their heads, fix their eyes on the ground and keep them lowered, but are unable to blush in acting shame." But what the will cannot do in this way, the emotion can. We gain very little by calling blushing an "involuntary" act, we gain much more by describing it as a reflex action due to emotion; we gain more, because we place this familiar action in its appropriate niche in the group of a very large number of allied actions.

The emotio-glandular reflexes are equally familiar, they are typical of mentally induced tissue-action. Weeping naturally occurs to one as an emotio-glandular reflex, but we have examples equally good in emotional perspiring and emotional dry mouth. The reflex through the skin-glands is a positive emotio-glandular reflex, that into the salivary glands is a negative reflex, in the latter case the emotional state has inhibited the activity of the glands which produce the saliva. The cold sweat of fear is an interesting reflex, because it is unaccompanied by any vascular factor; sweating usually occurring along with increased blood-supply to the sweat-glands. But this, as we see, is not invariable, for the glands and the vessels to the glands have a separate innervation; there may be emotio-glandular reflexes without emotio-vascular reflexes (cold sweats), and conversely emotio-vascular without emotio-glandular reflexes (dry flushing or blushing). Certain emotional states in the lower animals have glandular expressions, as when the skunk in fear protects itself from its enemies by reflexly stimulating its "stink-glands."

Finally in this group, we have the interesting sub-section, the emotio-metabolic. If the

Prisoner of Chillon's "hair turned white in a single night," it was not due to that unfortunate man's volition, but to an emotional reflex action. Darwin firmly believed in cases of the kind, and they have been corroborated since his time. He gives instances in his "Expression of the Emotions."

Just as emotional states can in a very short time reflexly affect the muscles, heart, blood-vessels and glands, so it is most reasonable to suppose that emotional states can in a more leisurely fashion influence the nutrition of hairs, nails, teeth and other structures. Certain dentists firmly believe, apparently on good grounds, that prolonged mental worry and anxiety causes the teeth to decay at a much faster rate than they otherwise would. If this can be satisfactorily proved it constitutes an excellent example of an emotio-metabolic reflex action.

We finally come to those bodily acts or conditions which, certainly not voluntary, are causally due to some purely mental state higher than emotion, though, of course, not necessarily destitute of emotional colouring. Any state of mind, not a sensation, nor an emotion, and not a volition, may give rise to a reflex action. We know how ideas may

take possession of the mind and express themselves in action apart from and often in opposition to the will. Such actions are called ideo-motor. Possibly these ideo-motor reflex actions are seen more often in the case of the insane than in persons of sound mind. Thus if a man imagines himself the Mikado of Japan, he soon assumes a carriage, a gait, appropriate, as he thinks, to this august person; he does this not by any deliberate act of will, but as part and parcel of his daily life; he is exhibiting, through his muscular system, a number of widespread, co-ordinated, ideo-muscular reflex actions.

The convulsions induced in the jaw-muscles of a patient with hydrophobia by the very idea of water, are ideo-muscular reflexes. Hypnotic phenomena are largely cases of ideo-motor reflex action; thus, when a man is hypnotised and told that shortly he will become cold or hot, he does in due time become whichever was predicted; that is to say, an ideo-vascular reflex has occurred, in one case of a positive, in the other of a negative order. The fixed idea, not the will, has been the cause of these states; they are not part of behaviour.

Similarly ideo-glandular reflexes may be induced most typically in the hypnotic state.

The subject is told that he must weep copiously, or that his mouth will become parched, and so on, and it all happens in due time. His weeping betokens behaviour no more than does his dry mouth; in the trance he is unconscious of all except a very few mental events. Glandular reflexes happen in him, but in spite of him, and he is not responsible for them; again they are outside behaviour.

Lastly, in the ideo-motor group, we encounter the ideo-metabolic reflex actions. Good examples of this class of reflex are seen in the case of insane persons in whom fixed ideas and other mental abnormalities, not characteristically emotional, produce distinct alterations in the nutritional states of the tissues. In fact, under the heading of ideo-metabolic or ideo-trophic reflexes, we enter the wide but ill-defined field of the action of mind on body, a field strewn with the wastage of many battles. We must not advance far into this topic, for if it is not in the province of behaviour, it is part of that of psychology; nevertheless as it is not the precise character of the mental element that interests us so much as the nerve mechanism of such achievements as are alleged in faith-healing and in things of that order, we may consider the

subject a little farther. Outside of the exercise of will-power, there are many instances of cerebral activity—ideas—influencing if not ameliorating the course of disease. Psycho-therapeutics is a department of the healing art likely to be more not less employed in the future. Without in any way accepting as beyond dispute the reality of cures at miracle-working spas or wells or shrines, or the marvels of recovery from illness described by the so-called "Christian scientists," we may admit that there exists in the nervous system a mechanism whereby ideas present in the mind can exert a real influence on bodily tissues and organs. We shall see later that such things occur in hysteria and similar states generally in persons often most deficient in will power; they are the victims of ideo-motor reflexes.

The element of time, as we have seen, is now known, contrary to what was formerly supposed, to enter into all activities of nerves and nerve-centres. Reflex time is the time-interval between the moment of applying a stimulus, and the moment at which the reflexly stimulated muscle contracts, for it is almost always sensori-muscular reflexes whose time-relations are thus studied. The

reflex time is the total time for impulses to traverse the entire reflex nerve-arc. In traversing this they traverse the centre, and the time occupied in that is "the time of central delay." As might be supposed, this is not estimated directly; it is calculated by ascertaining the total reflex time, and from that subtracting the times of the impulse travelling in the afferent nerve and in the efferent nerve. When this is done, there is always obtained a real time-value, no doubt in itself exceedingly short, but still a few fractions of a second, showing the extreme rapidity of neural processes. Thus taking the familiar flicking reflex in the spinal frog, the total time may quite easily be two to three seconds, the time of spinal delay is, for the frog, only about 0·015 of a second. It is interesting to find that the time of central delay is much longer if the reflex crosses the cord, as for instance when the left foot is stimulated, but the right responds. Accurate measurements have been made on the winking reflex in man by stimulating one eyelid and recording the jerk of the other, the times are for the total crossed reflex between 0·0578 and 0·0662 of a second, which gives for central delay between 0·0471 and 0·0555 of a second. We

learn from these and similar observations that the time occupied by central processes, instead of being practically negligible, is in most cases quite the longest element in the reflex action. It varies with the strength of stimulus and condition of the centre, being shorter with stronger stimuli, and longer in fatigue and after the administration of certain drugs, *e.g.*, chloral and the bromides.

Reflex time is sometimes even in text-books wrongly spoken of as " latent period."

CHAPTER V

FURTHER STUDIES OF REFLEX ACTIONS AND CENTRES: CO-ORDINATION

We have already seen that one of the characteristics of reflex actions is their machine-like constancy of expression, their inevitableness. Thus in the decapitated frog, as often as the acid paper is laid on the left flank, so often will the left hind leg be raised up and will flick off the irritating patch. In the spinal dog, as often as the skin about the left shoulder blade is irritated, so as to imitate the biting of a flea, so often will the left hind leg be brought up to scratch the spot. Now, if one was watching these movements for the first time, one would say, the frog wished or intended to flick off that paper, the dog was scratching its shoulder on purpose to remove the flea. Certain reflex actions look so full of design that they are described as the apparently purposeful. But not only so, suppose that the acid paper is on the frog's

left flank and you hold down its left leg so that it cannot be raised to flick off the paper, then the right leg will be brought up to do so. This looks still more as though it were done on "purpose."

Now suppose for a moment that the decapitated frog purposed to flick off the acid paper, how comes it that this burst of intelligence occurs amid the tremendous blankness of hanging for hours by a hook through its head, and never making one struggle to escape? Is its other general conduct compatible with intentional, conscious life? Are we to imagine for a moment that an animal, which will hang until it becomes a mummy, will suddenly in the midst of its life of mental nothingness wake up and resolve to remove a piece of acidulated blotting-paper? The very mechanical repetition of the reflex which goes on till the cord is exhausted, precludes our believing that it is intentional, however much it may seem so.

Similarly, can we for a moment suppose that there is consciousness in the spinal cord of the decapitated snake which will allow itself to be scorched by the red-hot poker? So long as the brain is there, both frogs and snakes will avoid stimuli which tend to

injure them. In these cases the brain is acting as an organ of conscious inhibition or restraint; conscious inhibition being one of its most important activities. The spinal cord, isolated from the brain, gives no evidence of any "spontaneous" activity; the brain does give such evidence even when severed from the cord: spontaneity characterises consciousness. We therefore attribute consciousness to the brain but not to the cord; these actions, therefore, that look so full of purpose are reflexes, complicated reflexes if you like, but still reflexes.

The spinal cord carries out complicated reflexes, *e.g.*, in the activities of walking and balancing oneself, in which there is purpose —intention to progress and maintain equilibrium, but the spinal cord is not therefore conscious of the purpose. When the lower half of the human spinal cord is severed by an accident from the upper half, the man is totally unconscious of all sensations connected with his feet and legs, but impulses from the lower limbs continue to ascend to the isolated half of the cord, though without arousing any consciousness.

Not only does there seem to be purpose in

reflex actions, but their precision, as regards place aimed at in the excito-muscular reflexes, is very striking. Thus the spinal frog unerringly brings its leg to the place of the acid paper, and the spinal dog as correctly finds out the place where the irritation, so like a flea, is situated. This accurate application of muscular movements to discover a small spot is part of the evidence of what we call co-ordination between the incoming and the outgoing impulses of the reflex actions. There is, in other words, a definite adaptation of the muscular response to the afferent message ; the latter is co-ordinated or brought into line with the former, and this with great accuracy. There is no haphazard fumbling, as it were, on the part of the muscles ; they answer to the message without undue delay, and with all due accuracy. Now this adaptation or co-ordination must depend on a very perfectly working intra-neural mechanism. As an example in man of accurate reflex action, we may take the case of a soundly sleeping person scratching a mosquito-bite. Such a person may know that the bite ought not to be irritated, and yet, while unconscious, the complicated reflex action for bringing up the fingers to scratch the irritating spot is correctly

carried out. In the morning he is annoyed that he has scratched the place; had he been conscious he could have restrained (inhibited) the reflex tendency. The afferent currents must run unerringly to the very cells which innervate the particular muscles involved in the action. The efferent part of the arc must be functionally connected very intimately with the afferent, else the incoming impulses could not so accurately pass from the one to the other every time. This functional linking of one neurone with another is a most important physiological occurrence; it is the physical basis of habits, of unconscious performances. We have no simple name for this basis of co-ordination; the German word is Bahnung, which means making paths or lines through something. Eisenbahn in German is "railway," literally iron way or road; so Bahnung in neurology means making ways through the mass of centres of the grey matter. The nearest English word for this process of forcing paths through a maze of centres is "canalisation," a term indicating the same sort of notion. Of course, there are neither rails nor canals, but the idea is the forcing and the maintaining of paths for nerve-impulses, paths or ways in which the

resistance to impulses is more and more overcome and finally reduced to a minimum. Functional path-making, is perhaps as good a term as any for the sort of thing that goes on when efferent neurones are functionally connected to afferent ones. Undoubtedly the establishing of functional paths is the physical basis of habits, for habits are but elaborate reflex actions. Instincts are inherited habits. A great many habits are ideomotor reflexes, many more are sensori-motor. The original establishing of a habit is accompanied by consciousness, but by degrees the conscious element is reduced to a minimum, and the action becomes more and more reflex, *i.e.*, is carried out on the subconscious plane. In determining a habit, not only does education (learning, acquiring) play a part, but there must be an inherited predisposition for functional pathmaking in the neurones about to be associated. Thus, the instant the chick just hatched sees a seed, it pecks at it, not perhaps with perfect accuracy, but in such a way as to make us believe that in its central nervous system there are at least potentially linked paths between the eyes and the muscles for pecking at seeds. No doubt the chicken learns much about pecking

seeds as time goes on, but no doubt also it is hatched with the grey matter of its central nervous system *canalised* for pecking actions. Functionally, we call these sorts of things inherited predispositions or potentialities; on the side of structure we say there are certain neurones pre-adjusted to become linked paths.

Neural path-making is, then, the basis of co-ordination of impulses; and co-ordination is absolutely necessary for the accurate accomplishment of any action, even the lowliest reflex. Once a certain reflex arc has been canalised, it offers less and less resistance to each successive discharge of impulses through it. If A and B are the two neurones so linked, then at any time thereafter, any stimulus which affects A generates impulses which flow into B more readily than into any other efferent route. When this path-making occurs within the regions of the central nervous system related to consciousness, it constitutes the physical basis of the association of ideas, just as when it occurs in the spinal cord it constitutes the physical basis of reflex actions and habits —many of the reflex actions so constituted being of a highly complicated nature.

Now, although any given impulse of a certain intensity travelling in A will preferably enter B, yet under certain conditions it *can* arouse to action neurones other than B: this sort of thing is called spreading of reflexes or irradiation. To take a case in the decapitated frog, if we place on one flank a very acid piece of paper, not only will the leg of that side be raised towards it, but the leg of the opposite side as well; in addition the arms are thrown into convulsions and the abdominal and flank muscles—in fact, the entire animal is in convulsions. Here, then, has been the greatest possible amount of spreading not only up and down the same side of the cord, but across the mid-line and up and down the other side. Here unusual strength of stimulus was the cause; it gave rise to such violent impulses that they overcame the resistance at the A B centre (synapsis) and irradiated widely through the other motor centres in the grey matter of the cord with the result that muscular groups more and more widely separated were thrown into activity. We might notice that except the activity of the legs, none of the other convulsive actions were "purposive"—the tremors of the muscles on the front of the body could do nothing to

get rid of the irritating paper. If the lifting of the leg towards the paper is a purposive act, then the general convulsions of the spinal frog are quite meaningless. But the lifting of the leg of the spinal frog is due to the path-making (Bahnung) of neurones A and B, while the violent stimulation of the more acid paper is best expressed as a "motor overflow" or more or less violent spread of impulses. The possibility of irradiation depends on the anatomical fact that the neurone A sends off many side branches or collaterals, as they are called, each of which (C) can actuate a discharging neurone (B). Thus in Fig. IV. we may suppose that the original path made was $A\ B_3$, but that there is the possibility of irradiation into B_1, B_2, B_4, B_5, and B_6 as well.

The irradiation we have so far studied has been supposed to be due to the excessive potency of the impulses distributed by A to B_1, B_2, etc., in the central grey matter of the cord. Now it is clear that if we suppose the strength of the impulses (stimuli) to remain constant, but only the affectability of the various cells, B_1, B_2, etc., to be raised, or, what comes to the same thing, their resistance lowered, then stimuli of ordinary strength

travelling up A will cause irradiation into the various discharging neurones B_1, B_2, etc. This is the sort of thing that happens when

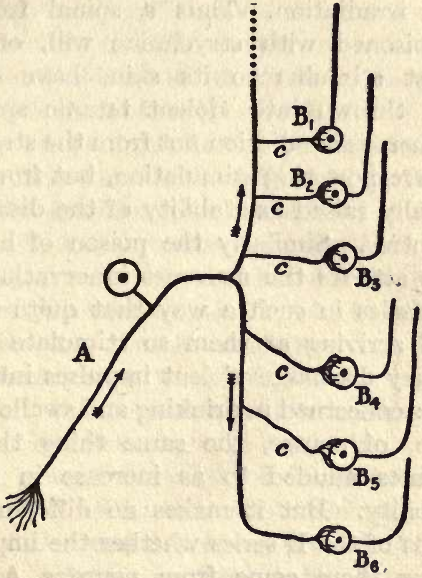

FIG. IV.—A an afferent neurone with headward and tailward branches and five collaterals *c* forming synapses at the centres B_1, B_2, B_3, B_4, B_5. The tailward branch ends at B_6.

such a poison as strychnine, is given to an animal. This substance fixes itself to the nerve-cells, and raises their suscepti-

bility to impulses to such an extent that even very slight incoming impulses throw many groups of muscles into spasm by wide-spread irradiation. Thus a spinal frog or dog poisoned with strychnine will, on the slightest stimulus to its skin, have every muscle thrown into violent tetanic spasms. Here there is irradiation not from the strength of an overpowering stimulation, but from the artificially raised excitability of the discharging centres. Similarly the poison of hydrophobia attacks the neurones innervating the jaw-muscles in such a way that quite slight stimuli arriving at them so stimulate them that they discharge violent impulses into the muscles concerned in drinking and swallowing. This is, of course, the same thing that is sometimes alluded to as increase in reflex excitability. But it makes no difference to the cells of the B series whether the impulses affecting them come from neurone A, *i.e.*, reflexly, or whether they come down neurones from higher centres. Such impulses may be voluntary or ideational (thought of water causing convulsions), in which case we should have spasm of the jaw-muscles as an ideo-motor reflex.

In perfectly normal states of the lower

centres of the nervous system, we may have instances of irradiation of emotional origin. Take the case of a man in what is called "a towering passion"; the violent emotion related to the unusual excitement in his cerebrum sends down violent irradiating impulses to motor centres of the B series (Fig. IV.), which being greatly stimulated throw many muscular groups into convulsions. The angry man is not only exhibiting violent emotio-muscular reflex actions, but also the phenomenon of irradiation on a large scale. These irradiations are sometimes called "motor overflows."

Rarely are neural discharges entirely inco-ordinate even when irradiation is most marked. Irradiation does not mean the same thing as a chaos of neural discharges. Even in the general overflow of impulses in the spinal frog with the very acid paper, it is the flexor muscles which prevail over the extensor, whereas in the strychnine poisoned frog it is just the opposite, the extensors prevail over the flexors. But all is not confusion, not even in the paroxysm of rage: there is a co-ordinate outflow of impulses into particular muscular groups which especially "express" the emotion of rage. As is well known, the particular muscles expressing

certain emotions were carefully studied by Darwin, who has left full details of the physiological anatomy, as it were, of emotional expression. It is certainly an interesting problem why a certain emotion, rage for instance, should draw back the lips, while sorrow should let the corners of the mouth droop, why each emotion should have got associated with a particular muscular group and no other. It is a case of very definite functional differentiation.

To appreciate the full import of what is happening in the nervous system when spinal or other co-ordination is being carried out, let us take the simple case of only two groups of opposed muscles concerned in the movement of some joint or other.

Every one knows that a joint can be bent (flexed) or unbent (extended) by the flexor muscles and extensor muscles respectively. Consider the elbow-joint; we know that it is the biceps muscle which bends (flexes) the elbow, and that it is the muscle at the back—the triceps—which unbends the joint. Clearly these muscles are antagonists, that is, are occupied doing exactly the opposite of each other: now it is just this that in the normal states of the central nervous system

they are prevented from doing. Muscles called physiologically antagonistic would really be better called mutually adapted or co-ordinated. Referring to the diagram (Fig. V). where the conditions are reduced to their simplest expression; let Fl be a flexor group and Ex an extensor group of so-called antagonistic muscles, and let Y be the neurone

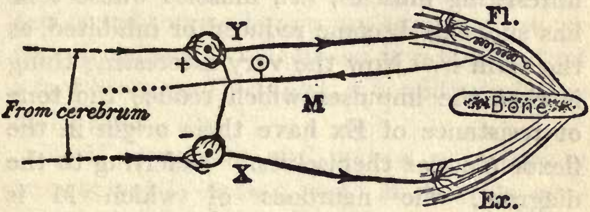

FIG. V.

innervating Fl and X that innervating Ex. Suppose that the elbow-joint is first of all straight out, and that it is desired to bend it, then clearly the biceps must contract to pull the forearm towards the upper arm (humerus), but unless its antagonist—the triceps—is at the same moment made lax (inhibited), the joint cannot be smoothly and swiftly closed as we know to be possible.

Voluntary motor impulses are evidently to be sent to Fl *via* Y, but if this were all that

descended from the brain to the spinal centres, there would not be the co-ordination between Fl and Ex which we know occurs. What has been discovered to take place is this: at the instant when Fl is caused to contract, the muscle Ex is caused to relax so that the active flexors have not to pull against resistent antagonists, but against unresisting muscles, *i.e.*, muscles whose tone has suddenly become reduced or inhibited, as the term is. Now the very interesting thing is that the impulses which reduce the tone or resistance of Ex have their origin in the flexor muscles themselves. Referring to the diagram, the neurones of which M is one, which arise in the flexor muscles, travel up to the region of the spinal cord centres and there so influence the centre X that its tone or tonic activity is depressed, and therefore the tone or tonicity of Ex itself. This curious, mutual adjustment between two antagonistic muscle-groups is known as "reciprocal innervation." It is convenient to mark these simultaneous and opposite effects on the centres Y and X by a + and — respectively. This simultaneous excitation at one centre and inhibition at a functionally related one is one form of co-ordination, the

form where inhibition makes way for contraction, and where contraction occasions inhibition: it is neural mutual adjustment.

When one muscle-group cannot or does not work without the simultaneous activity of the other, the condition is mutual co-operation, a condition of two pluses (or more technically, synergism); when one muscle group works simultaneously with the inactivity of some other group, as in the case we first described, the condition is rather mutual adaptation, readjustment, a condition of plus and minus.

Both synergisms and mutual adjustments are constantly taking place in order to constitute the duly co-ordinated activities of the central nervous system. Thus, in walking, there is synergism as regards the various muscles which prevent the head falling forwards; but as the right leg is moving forwards to take its step by the activity of the long muscles passing from body to thigh, the muscles at the back of the thigh are simultaneously relaxed to allow of the leg's forward thrust. It is clear, too, that what at one moment is a particular distribution of + and — will be all reversed at the next to permit of the opposite phase occurring: what was plus is

now minus, and *vice versa.* We shall revert to some of these problems in a later chapter on Inhibition. A few examples of synergism and mutual adjustment may be useful.

A man is about to raise a weight or otherwise exert limb or body muscles; it is noticed that at the moment of exertion his jaw muscles act and clench his teeth. When the diaphragm descends to enlarge the chest and so suck air into the lungs, the muscles of inspiration which raise the ribs go into activity at the same moment: the diaphragm and the intercostals act synergically. As regards the opposite condition; when the blood pressure ought to fall, owing to the heart acting too strongly, the muscle of the heart sends a message to the central nervous system to the centre for the blood vessels, whose tone is decreased (inhibited) so that the circular muscle of the arteries relaxes. When the jaw is to be opened, the muscles in the floor of the mouth contract, but the strong muscles which clench the jaws (temporals, masseters, etc.), are relaxed. Functional phase must, then, be capable of rapid alternation from plus to minus, and minus to plus, and so on in quick succession. We can make our fingers quiver rapidly; in fact,

we can flex them and extend them ten to twelve times a second. Now this means that the flexor group can be activated ten to twelve times and inhibited ten to twelve times each second, and similarly for the extensor, so that we have in flexors ten plus and ten minus phases a second, and in extensors ten minus and ten plus simultaneously: *i.e.*, there is in any one muscle-group a rhythm in activity, a functional oscillation of the living matter from the plus phase to minus phase at the rate of ten or so per second. But if the muscle-group is thus functionally oscillating so many times per second under the influence of innervation, which it clearly is, then the motor neurone itself must be oscillating functionally at the very same rate. In other words ten nerve impulses to contract and ten not to contract must be descending any one efferent musculo-motor neurone in order that under the influence of voluntary innervation any muscular group should oscillate at ten per second. This is the physiological innervation-rhythm, a point to which we shall revert when considering the innervation of tone: the activity of the motor centres can be expressed rhythmically.

We appear to be justified in concluding

that the state of any given centre can vary from time to time—perhaps from moment to moment—in its physiological properties. At one instant it is in activity, at another at rest; at one time it is fresh and "fit," at another fatigued or worn out; at one moment its affectability is high, at another low; or, otherwise put, its resistance or functional inertia to currents is low at one moment, at another high; at one time it is under the influence of substances of chemical nature, at another it has eliminated them. Now different centres vary amongst themselves in regard to their physiological properties. Taking relative susceptibility towards those chemical substances which are associated with fatigue, about which we shall learn more in Chapter VIII., we see that the cells of the cerebrum related to consciousness are much more easily brought under the influence of fatigue than those which make up the centre for breathing. Clearly it would never do if the respiratory centre could become fatigued, for we have to breathe day and night, waking and sleeping, all our lives. While the centres for vision or hearing or for memory may be utterly tired out, the centre for breathing must be still active.

The centre for breathing has a special sensitiveness, which the others do not possess in the same degree, towards the gas carbon dioxide. Recent researches have shown that the respiratory centres are far more susceptible to the presence of CO_2, or of acid or lack of oxygen, than are any of the centres in the spinal cord. The meaning of this is very clear: the respiratory centre presides over those movements which have as their object the getting rid of carbonic acid gas and the taking in of oxygen, so that it ought to be very sensitive to variations in the amounts of these two gases in the blood. But all the centres in the spinal cord are not equally affected by the same substance, for amounts of carbonic acid gas, which excite the cells of the spinal vaso-motor centres, leave the cells of the musculo-motor centres unaffected.

Again, the lack of oxygen in the blood excites the centres for the muscles far more than does an increase in the carbonic acid gas. The order of susceptibility to asphyxia (poisoning by carbonic acid gas) is as follows: the chief vaso-motor centre in the medulla, next the centre which controls the heart, then the respiratory centre, and lastly the

spinal vaso-motor centre. Hence the various centres react differently to the same poison. It is also well known that the various sets (or groups) of nerve-cells have very different powers of resistance to the same degree of anæmia or partial bloodlessness.

Nerve-cells (centres) have, then, different chemical susceptibilities; so that in the recesses of the nervous system it is as true as it is of the organism as a whole, that, "what is one man's meat is another man's poison." The relative differences in susceptibility or vulnerability are well known in the case of the effects of heated blood on nerve-cells, the brains of some people being damaged by a temperature which does not injure others; the former get sunstroke, the latter do not. For "sunstroke" is wholly due to the hot blood injuring the cells of the central nervous system: *i.e.*, it is the heat, and not the sun as such that does the damage. Stokers can get "sunstroke" (heat-stroke) in the furnace room of a steamer in the Red Sea, without even seeing the sun. From the various degrees of susceptibility to sea-sickness on the part of different people, we see that the same centre in different people is not equally susceptible to the same amount and quality of

stimulation. This, of course, is the neural basis of idiosyncrasy.

But further; on comparing one man, woman, or child with another we see the greatest possible differences in the susceptibilities of the nerve-centres to drugs, poisons and bacterial products (toxins). Suppose that an epidemic of influenza is raging, A will be badly infected, B slightly, C not at all. The cells of C's nervous system are evidently naturally refractory towards the toxin peculiar to the bacillus of influenza, whereas A's are just the contrary. This may be an inherited insusceptibility as regards C, an inherited susceptibility as regards A, or either condition may have been acquired. It is known that persons suffering from indigestion, or when "run down," are much more liable to catch infections than their neighbours in better health.

Finally, in any one animal there are great differences in susceptibility towards any one poison on the part of the various centres in its nervous system. Thus as regards rabies, the point of attack by the poison is certain cell-groups innervating the muscles of the palate and of swallowing, while other closely associated cell-groups are unaffected. The

poison of diphtheria attacks, in particular, cells innervating the muscles of the palate, so that a child who recovers from a bad attack may have "post-diphtheritic paralysis," a falling of the palate which affects his speech, giving it a nasal character and also interfering with the power of swallowing. We know, too, how the poison of tetanus or lockjaw affects especially the centres governing the muscles which clench the jaws, affecting them much more seriously than other nerve-cell groups.

The doctrine of centres finds, then, strong confirmation in the light of the various sets of facts which have just been before us. For the sake of clear thinking let us summarise the various ways in which a centre may be stimulated. Let us take the case of any typical centre in the brain-stem or cord. It can be stimulated thus:—

1. By impulses descending from the higher levels of the nervous system, *e.g.*, psychic impulses from the cerebrum.

2. By impulses ascending from the surface; producing reflex actions (in the usual acceptation).

3. By chemical agencies.

4. By direct mechanical irritation of its cells.

Suppose we consider the case of the centre for perspiration in the medulla oblongata. Ideational or emotional impulses descending on it will produce perspiration usually accompanied by flushing; impulses from such a condition as heat to the skin or great pain from some internal organ reaching it reflexly will induce sweating. But the perspiration centre can be stimulated by chemical means, as when we administer the drug pilocarpine for the purpose of making the sweat glands act: this drug (also known as jaborandi), besides acting on the centres, acts on the terminations of the nerves in the sweat-glands and in the hair follicles, for hairs grow rapidly provided their follicles are intact.

To illustrate direct mechanical stimulation of the cells of a centre, we might take the cases of the centre for slowing the heart and the vomiting centre. Inflammation of the medulla oblongata, which produces pressure on the cells of the centres in it, or pressure within the skull as the result of purely mechanical conditions, has the effect of stimulating both these centres, and the heart is slowed and the person has an attack of sickness.

The vomiting centre is indeed an excellent

example of all the ways in which a centre can be stimulated: it can be stimulated by mental states such as emotions or by sensations, such as the sight or smell of something disgusting; it may be stimulated reflexly, as in pain involving some internal organ; it can be stimulated by apo-morphine injected into the blood and by other substances with active chemical properties; and, finally, as we have seen, it can be stimulated by the mechanical irritation of pressure.

Thus we have sickening sights, smells, and pains, drugs which induce vomiting (emetics), and even mechanical sources of vomiting. The stimuli are many, there is but one property of response on the part of the centre, its affectability. Why certain stimuli should arouse nerve impulses which travel to and affect the vomiting centre at one time, the cardiac at another, or the centre for the blood vessels or for perspiration at a third, is one of these problems which in the present state of our knowledge of the working of the nervous system must be looked upon as not solved, but which no one should call insoluble.

CHAPTER VI

THE IMPULSES ENTERING AND LEAVING THE NERVOUS SYSTEM ; TONUS ; RHYTHM

If what has been said in the foregoing chapters has been followed, it will be evident that the conception of the nervous system which we should have is that of myriads of ingoing neurones incessantly carrying inwards and upwards multitudes of impulses from the periphery and pouring them upon thousands of cell-bodies or centres in the grey matter. These centres, thus roused to activity, discharge outwards streams of impulses destined for the innervation of muscles, blood-vessels, heart, glands, and other tissues.

Let us look, first of all, at the various tissues whence arise these afferent impulses. Possibly some of us have not any adequate idea of the variety of kinds of sensory impressions and of unconscious afferent impulses which are continually entering the nervous system. A good many people seem to think that they

have only five senses out of which they can be startled, but the number as at present recognised is more like a dozen. Now what constitutes the difference between one kind of sensation and another? How do we know when we have discovered a new kind?

We recognise a sensation in two ways. First, in consciousness, by deciding that it is different from any of the kinds we seem to possess, the old familiar five being, seeing, hearing, smelling, tasting and touching; and, secondly, by discovering with the microscope special organs—end-organs—the presence of which is absolutely necessary to the existence of the sensation. Of course, everybody knows we see by the eye and hear by the ear, and so on; but, deeply placed in these organs of sense—eye, ear, nose, etc.—are minute, living, protoplasmic structures characteristic of each sense-organ respectively. Thus in the eye there are rods and cones of the retina, in the ear there are hair-cells and so on, all of which are fully described in works on the Senses. Now it is these microscopic end-organs which are different in detail in the case of each sense. The microscopist distinguishes the type of end-organ in the eye as quite different from that in the ear,

nose, tongue, finger-tips, muscles. Besides impulses pouring in from the end-organs of sense proper, we have a vast number of impulses arising in less specialised end-organs, and in some cases none at all, naked afferent nerve-fibrils being directly stimulated by the presence of the fluids of adjacent tissues. Afferent impulses, then, pass upwards whether from definite receivers or from nerve-terminals unprovided with these. The sensory end-organs are receivers of some special form of stimulation which they transform into nerve-impulses for ascent to the central nervous system. The sensory end-organs proper, or "external" senses, are related to changes in the outer world, the rest of the afferent nerves being related to changes in the body itself. Thus the rods and cones of the eye transform light-waves into nerve-impulses, whereas certain end-organs in our muscles transform muscular pressures into nerve-impulses; by means of the former we say we see an external object, by the latter we are aware of the activity of our muscles or of the resistance offered to their efforts.

An interesting example of the physiological value of transformation of stimuli into nerve-impulses is a phenomenon pointed out long

ago by Marshall Hall. If one stimulates, say, electrically, the skin in the left foot of a spinal frog, and notes the magnitude of the stimulus required to bring out a reflex action, it will be found that a stronger stimulus when applied to the naked nerve itself, will be needed to bring out the same strength of reflex action.

Otherwise put, stimuli after transformation through the proper end-organs are more efficacious in bringing out response than are stimuli untransformed into nerve-impulses, In fact, only nerve-impulses are the proper stimuli for nerve-fibres; any other sort (pressure, chemical action, electricity, heat, cold) are unphysiological for the nerves themselves. Thus, the mechanical stimulation to the nerves of the teeth when the tooth is pulled out gives rise, not to any dental sensation proper, but to pain to correspond to the unphysiological stimulation. But organs, not usually thought of as possessing sensation at all, the lungs, heart, stomach, etc., can yet make us more or less dimly aware of their existence, usually indeed when they are "out of sorts." This they do, not through any definite terminal apparatus, but by being provided with afferent nerves

which are stimulated only in abnormal and painful conditions. Then, more vague still, are such sensations as hunger, thirst, the feeling of being well, the feeling of being ill (malaise), which certainly are related to states of tissues, for it is tissue-nutrition that determines hunger, thirst, and the like.

Summarising the sources of afferent impulses as regards their sites of origin we may say they are of three kinds, namely—

First, those receiving stimulation from external sources, or the extero-ceptive;

Secondly, those receiving stimulation from internal organs, or the entero-ceptive; and

Thirdly, those receiving stimulation from the states of the tissues themselves, the proprio-ceptive.

The extero-ceptive are also called distance-receptors, since they have to do with sensations aroused by forms of energy present in the outer world, and it may be coming from sources very far away: the entero-ceptive and proprio-ceptive inform us about changes in our own bodies. All these receptors are transformers of energy; the extero-ceptive transform light, sound, chemical activity, into nerve-impulses; the entero-ceptive transform, for the most part, internal pressures

into nerve-impulses, many of them painful; and the proprio-ceptive transform pressures and tissue-states into similar impulses. When we use the word "receptor," we do not make it mean only end-organ of *sense*, receptors are specialised neural mechanisms for transmitting impulses into the nervous system, impulses which may or may not arouse sensations. A complete list of the distinct sources of afferent impulses known to us may now be conveniently given—

I.—*Extero-ceptive receptors:*

(1) In the retina of the eye (rods and cones), concerned with the senses of light and darkness (luminosity), form or outline and solidity, and finally colour differences; vision and colour-sense.

(2) In the cochlea of the ear, hair-cells concerned with hearing and discrimination of the pitch of notes.

(3) In the mucous membrane in the upper part of the nose; hair-cells concerned with the sense of smell.

(4) In the mucous membrane of the tongue and palate; hair-cells concerned with the sense of taste.

(5) In the cutis or true skin, special corpuscles; and in the epidermis free nerve-

endings related to the senses of true touch, heat and cold, pressure and pain.

II.—*Entero-ceptive receptors:* those concerned with afferent impulses from the heart and other internal organs when active—occupied with internal (visceral) pain or vague general sensations (common sensation, hunger, thirst, etc.).

III.—*Proprio-ceptive receptors:* those in the interior of muscles (muscle-spindles) which, when stimulated give us knowledge of the state of activity of muscles; the muscular sense.

Those in the neighbourhood of joints, ligaments and tendons; the joint or articular sense.

Those in the interior of the labyrinth of the internal ear (vestibule and semi-circular canals), which, when stimulated, cause afferent impulses to ascend to the cerebellum and other parts of the brain.

We see, then, that there are upwards of twelve varieties of qualitatively different sensations, the afferent currents producing which are more or less constantly ascending to the central nervous system. Further, it is interesting to know that the microscopists have found that there are actually many more afferent than efferent fibres in the spinal

nerves. In the roots of two spinal nerves investigated there were 5,335 afferent fibres as compared with 4,283 efferent, or about 17 per cent. more. Not only are the ingoing neurones numerically the more important, but they are the earlier in developing in order to become functionally active. In the case of medullated nerves, the acquiring of the fatty or medullary sheath is the sign that the neurone is ready to transmit impulses; now the afferent neurones of the spinal cord are medullated some months before the efferent. Further, the neurones of the sensory centres in the brain are medullated before those of the motor centres. The meaning of all this is not very far to seek: there must be incoming of impulses before there can be the outgoing; the mind must receive before it can give out, centres must take in before they emit. But what is it that is given out from spinal cord and brain? There is only one answer, nerve-impulses. If nerve-impulses pour in, they also pour out, they must pour out, they cannot be bottled up. It does not follow that they go out exactly as they came in, either in intensity or rhythm, but if myriads go in, myriads must go out. Impulses called visual, auditory, tactile, olfactory, gustatory,

muscular are pouring in as qualitatively different, and are influencing centres in the cord and in the brain. In the brain, under usual conditions, consciousness is qualitatively affected; there are as many different kinds of sensation as there are end-organs; in the spinal cord, the impulses, though they do not induce sensation, affect the centres there as truly as though consciousness had been aroused. Impulses which have arisen in proprio-ceptive end-organs and only vaguely affected consciousness, impulses vague but often painful from entero-ceptive organs, and impulses which never arouse consciousness, alike pour into the central nervous system. Whatever be the kind of receptor stimulated, it acts as a transformer (into a nerve-current) of the more or less special stimulation received. These impulses of manifold origin are not lost, cannot be lost in the recesses of the nervous system; they must effect some result, whether or not they give rise to sensations they must contribute to something, and that something is, in the end, the outpouring of efferent impulses. We must regard the centres as pouring down streams of impulses on to muscles, to the heart, blood-vessels, glands and almost certainly other

structures. This is innervation; it is being attended to by the nervous system. Whether the incoming impulses do or do not arouse consciousness they all contribute to this general efferent discharge, this outflow of impulses to innervate tissues. The tissues which most obviously receive this constant attention on the part of centres are the muscles; the centres and the impulses they emit may therefore be called "musculo-motor." But if receptors everywhere are receiving stimuli and constantly transforming them into nerve-impulses, and if impulses are as constantly arriving at muscles (and other tissues, as we shall shortly see), then the whole mechanism is a reflex one. It is indeed reflex, and the mechanism we are considering is known as that for the maintenance of muscular tone (tonus).

The muscles are in tone even when at rest, because multitudes of impulses are pouring into them from their motor centres. The proof of this is not difficult. If any part of the arc be cut or destroyed, the muscle loses tone and becomes flaccid. Of course, if the efferent nerve were to be cut, or if the centre were to be destroyed, the muscle would be toneless, as has been known for a

very long time; but it has been lately shown that if only the afferent nerves coming from a limb be cut through, the limb loses tone and the muscles elongate as compared with those of the normal limb of the other side. Now cutting the afferent nerves can only have the effect of cutting off the incoming impulses, and since their being cut off has the effect of diminishing the tone of the muscles, incoming impulses are necessary for maintaining the tone normally. The structural integrity of the reflex arc is necessary for the upkeep of full muscular tone.

But, clearly, the arc might be intact and yet if sufficient impulses or sufficiently intense impulses did not travel over it, muscular tone would be diminished. This is what happens when impulses coming up are prevented passing through the centres by reason of the resistance there being raised by fatigue; they will not transmit the impulses but block them, and so prevent them reaching the muscles. We know the tonelessness of tired muscles, it is as much the result of tiredness (tonelessness) in their centres as in themselves. As fatigue comes on, the tone of the muscles is diminished so that the thoroughly tired out man is like to drop, and he drags his

legs instead of using them alertly. In this connection it has been correctly observed that, when tired, one stumbles over an obstacle which would have been carefully avoided if the muscles had not been so lifeless; for tone is an expression of vitality.

When a drug such as chloroform attacks the centres, the muscles become flaccid; here again the narcotic has lowered the tone of the nerve-cells, partially poisoned them, and so prevented them transmitting impulses to the muscles. Alcohol, too, has a similar effect; we know how tonelessly intoxicated men fall, their muscles are flaccid because their poisoned centres are emitting impulses feebly, innervating feebly. Since the drunken man's muscles are flaccid, he rarely injures himself in falling, as he exerts very little muscular strain on joints and bones, hence the Scottish saying, "Providence is kind tae bairns and drunk men."

Children fall tonelessly because their brains do not send down emergency messages to the body-muscles to go into spasm in face of a danger which is practically unperceived.

We then must believe in neural tone, the tone of nerve-centres, that is of nerve-cells themselves, tone kept up by incoming im-

pulses, but lowered by fatigue, chloroform, alcohol and many other drugs. When sensory centres are deprived of their streams of incoming impulses, they express their loss of tone by going to sleep. An excellent example of this sort of thing is the case of "Strümpell's boy." This boy was insensitive to touch, had no muscular sense or senses of smell or taste, he had no sense of pain, he was deaf in the right ear and blind in the left eye. If now his left ear was stopped up and his right eye bandaged, he fell sound asleep in two or three minutes. Persons whose sensory content is very limited through rudimentary education, for instance Russian peasants, fall asleep very easily. One of the results of solitary confinement is the great depression which sets in in consequence of the cutting off of sensory impulses; the mind cannot remain a blank, and in some cases it becomes unhinged altogether when day after day it receives no fresh impressions. The continued cutting off of stimuli results in a great depression of the centre. The maintenance of muscular tone is, then, a reflex affair; and while important currents arise in the skin and sense-organs, the most important afferent impulses in the mainten-

ance of muscular tone arise in the muscles themselves. It has now been fully proved, that it is a muscle-to-muscle arc that is involved in the maintenance of muscular tone. An exceedingly interesting observation in this connection is, that if the afferent nerve from a given muscle be cut and its central end electrically stimulated, the tone of the muscle in question is at once raised. In other words, activity of a muscle exalts the tonicity of that muscle (Fig. VI.).

Is then all muscular tone due to innervation, is there any non-neural factor ? All muscular tone is not due to innervation, there is a non-neural factor in muscular tonus. Thus, if the afferent nerves be cut, some muscular tonus vanishes, if later the efferent nerves be cut more tone vanishes, but there is yet some tone left, this residual tone is purely muscular (autogenic).

Unless the muscle is thoroughly and regularly exercised, this purely muscular tone will eventually disappear ; and the watery, soft, flabby muscle be absorbed. There is a form of muscular tonus closely dependent on neural tonus, the tonus of what are called sphincter muscles, powerful, circularly disposed muscles which guard the outlets of

certain hollow internal organs. Destruction of the spinal cord at once causes these sphincters to relax tonelessly; later they regain some, not all, of their tone.

But, of course, tonus is not confined to muscles; a very great deal of the tone of the blood-vessels is dependent on innervation.

If the vaso-motor centre be destroyed, the vessels will dilate, lose tone; if the subsidiary centres in the cord be next destroyed, the vessels lose more tone, retaining only the inherent portion. The tone of the heart-muscle is closely bound up with its innervation, in particular with the integrity of the inhibitory nerve of the heart, a branch of the vagus or tenth nerve of the head.

If this nerve be cut, the heart-muscle degenerates and wastes away. Thus the

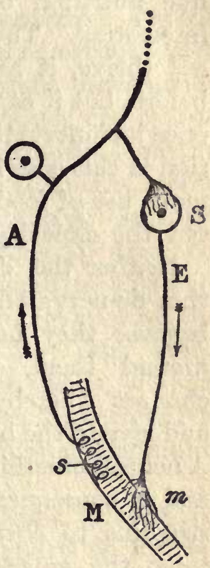

FIG. VI.—A, the afferent neurone arising in muscle in a sensory organ S ("proprio-ceptive"). E, efferent neurone ending on muscle in motor end-plate, M. S, synapsis at centre.

vagus may be called the trophic nerve of the heart, that is the nerve on which depends the due nutrition of the heart. This point is interesting. The non-innervated heart does not thrive, it has blood and nourishment as before, but it cannot make full use of it when once its innervation has been cut off. Innervation in this case is not food, but the power to make use of food, innervation is not strength, but the capacity to obtain strength.

Neither the de-nervated body-muscle nor the de-nervated heart-muscle thrives, not because they have not plenty of blood all around them, but because the chemical changes whereby they take from the blood and give to the blood have been compromised. A neural something has been taken from them, and in consequence of the withdrawal of this stimulus to chemical activity, expressed as tone, the muscles fail to make proper use of the nourishment all around them; the initiative to act, to take in, is gone.

The management of an army is a good analogy with the working of the nervous system. The army council, a few men, we may liken to the highest parts of the brain; the Intelligence Department and signallers to the afferent nerves, the rank and file of the

soldiers to the muscles, the ultimate executants of the orders issued by the council. The soldiers, of themselves, would never engage in any plan of concerted action. They must be drilled; made to execute first independent and then corporate movements in accordance with definite orders, the meaning of which they have previously learned. The men must be arranged in squads, companies, regiments and battalions, and go through manœuvres from time to time to practise what would be required of them in actual warfare (muscular synergism and co-ordination). But in order that the army council may issue appropriate orders, it must be kept informed as to the condition, number and distribution of all the units composing the army (afferent impulses).

The soldiers are the muscles, if left to themselves, that is, not attended to by the central nervous system they might act spontaneously from time to time, but not always in a manner calculated to promote the well-being of the organism as a whole, of which they form constituent parts. The men must be drilled by sergeants, who take orders from junior officers, who obey superior officers, who, in turn, receive orders ultimately

emanating from the council at the War Office (hierarchy of centres of different functional importance). Indirectly, then, this council issues orders to each individual soldier in the army. Similarly the brain is in touch with each muscle, which it drills and exercises and keeps in readiness for future activity, a state we call tone. The muscles, if not in constant functional connection with the nerve-centres, would become toneless, slack, unready to contract when a motor impulse, a command to action, arrived. But the very opposite is what we find; innervated muscles have a certain degree of tension, being ready to shorten after only an exceedingly brief time from the instant of receiving the message (latent period).

Muscles not thus innervated, even though well supplied with blood, would not be in a perfect state of health, would become a law unto themselves, and therefore be unrelated to their neighbour's needs. Tone is being kept in readiness to do work. Innervation is not the commissariat; the blood is the food—the canteen; each muscle must absorb its own nourishment, but by means of innervation it will be kept absorbing nourishment and ready for action. Innervation is each

soldier's knowing that those in authority over him have not forgotten about him, that his food and all else is being attended to. He is in a state of tone, that is, he is ready for action.

The outflow of what we may conveniently call tonic impulses has nothing to do with our consciousness; although diminished in intensity during sleep, tone is not abolished. To maintain tone we do not consciously innervate our muscles, they are reflexly (subconsciously) innervated. When the nervous system dies, the muscles take on the flaccidity of death before they enter upon the rigidity of death (rigor mortis).

We have seen that active muscle reflexly maintains its own tonicity, but that is only another way of saying that active muscle maintains the tone of certain nerve-centres themselves. It has lately been said that the muscles are constantly pumping energy into the nervous system; we ought now to be able to appreciate the truth contained in that statement which seems at first sight very strange.

The evidences of tone in muscle are, its resistance to tensions, torsions, squeezings, its taking in oxygen and giving out carbonic

acid gas, and that it gives out heat both in rest and in activity.

But physiological enquiry into the condition of muscular tone has revealed a further fact, namely, that tonic muscles are in a state of thrill, in excessively minute vibration or tremor. This thrill is not to be detected by the fingers or by sight; but from the results of several lines of study we believe that it has a periodicity of about ten to twelve a second. Now it has been long known that in that active state of muscle when we will to contract our muscles in a continued steady pull or push or lift, the muscle is vibrating (thrilling) at a rate which is something of the order of ten to twelve a second. This is called in physiology "the voluntary tetanus," and it is an oscillatory state of the muscle of such a degree of coarseness that the vibrations can be registered directly by communicating them to an indiarubber membrane. Now, since the rate of vibration of contracting muscle actuated by the will is the same as that of muscle in full tone, that is, innervated but inactive, we seem justified in believing that the tremor of tonus and the tremor of contracting muscle are essentially the same things, the one being a feeble version of the

other. We might call contraction exaggerated tonus, and tonus the minimum of contraction. The notion is that the muscle is always in tonus and thrilling under innervation at ten to twelve a second, the instant the voluntary impulses arrive at it, it springs into activity at the same rhythm, only now instead of thrilling imperceptibly at ten to twelve a second it is vibrating much more obviously. The voluntary thrill we can always hear if we clench our jaws with one ear on the pillow in the silence of the night: what we can hear giving out a low booming note, must be vibrating. Both tonus and contraction of muscle are then rhythmic phenomena. But if muscle is constantly in a state of rhythmic oscillation, either in tonic tremor (rest), or in contraction tremor (activity), it must mean that the cells of the centres for the muscles must also be in some corresponding state of functional vibration. Presumably muscle is in a tremor of ten or so a second, because nerve-impulses descend on it at that rate, but if they descend on it at that rate it must mean that the nerves are discharging rhythmically at the same rate.

There is, therefore, presumably, a neural or neuronic rhythm, the cause of the muscular.

Now there are other ways of testing the truth of this assumption. Let us, first of all, see how fast the cells of the spinal cord can send out single impulses to jerk a finger up and down. Take the case of the forefinger; how fast can the ordinary person (not the skilled musician) perform tapping movements per second? The answer is ten to twelve a second. Once again we seem to have to assume that the cells of the musculo-motor efferent neurones discharge single impulses at about ten a second, and under ordinary conditions cannot do so any faster. This rate is, then, the same as that of the rhythm of tonus and of voluntarily contracted muscle.

Now as regards voluntary impulses, we know nothing of their character, nor even whether they have a rhythm, but we know this much, that if voluntary impulses are rhythmic and if that rhythm is greater than about ten a second, it is transformed at and by the cells of the spinal centres into a rhythm of ten to twelve a second. Corroborative of this we find, that if we stimulate any points between the brain and the spinal cord centres with shocks faster than ten to twelve a second, the cells of the cord always transform these higher rates into their own (ten to twelve), but that

if we stimulate at any rates slower than ten to twelve, the cord cells follow the slower rates, shock for shock. In other words, the cord cells can follow, that is, emit at, rates from one to twelve a second inclusive, but when that limit is passed, they cannot discharge any faster than twelve; and no matter how much faster than twelve they are stimulated, they fail to respond, and merely maintain their own inherent rhythm. This inability to follow rhythms faster than a certain rate and to be, therefore, irresponsive to stimuli at rates faster than a particular figure, is one expression of what we may call the "functional inertia" of nerve-cells.

It would be a mistake to confine tone to muscular tonicity; there is as truly a tone of heart, blood-vessels, glands, skin and other structures. In the first place, these tissues are richly provided with nerves, and no structures are absolutely useless.

We know that the tone of glands is closely bound up with the integrity of their nerves; some glands after their nerves are cut, secrete a poor, thin, watery fluid in place of their proper, rich secretion.

The importance of nerves for the salivary glands, stomach glands, intestinal glands,

and sweat glands, has in recent years been increasingly recognised. The importance of the various reflexes expressed through them, excito-, sensori-, and emotio-motor, is fully acknowledged. There is, then, tissue-tone or chemical tone, the older term for which was trophic tone or trophism. Now, whereas we no longer recognise nerves only and entirely trophic, we fully admit that the efferent nerves to tissues convey to them constantly such impulses as are essential to the health and nutrition of those tissues. The maintenance of these other forms of tonus is just as reflex as is that of muscles. Although the maintenance of the tonus of centres in the cord and brain-stem is fundamentally reflex, yet the full tonicity of these centres depends also on the inflow of impulses from the brain proper, from that great layer of grey matter known as the cortex, the seat of sensations, memories, emotions, and volitions. In other words, the full tonicity of the lower centres does not depend only on impulses which have arisen at the periphery, but on the descent of impulses from the brain itself as an accessory factor. These impulses do not involve consciousness; the higher outflow is pre-eminently an unconscious one. It is from

the cerebellum as well as from the cerebrum. In the case of heart, iris, and certain other organs, tonicity is maintained by the due co-operation of two antagonistic innervations. As for the heart, it has two sets of nerves, one raising, the other lowering the energy of its activity ; and the presence of both is necessary for the highest cardiac efficiency. The heart is, as it were, functionally balanced between two opposing streams of nerve-impulses which are so delicately adjusted that a very slight excess or diminution in the innervation from either source profoundly affects the beat of the heart. The same is true of the iris, and of the muscle of stomach and intestine.

This two-sidedness of tissue-activity has at all times to be remembered. It seems that tissue-activity is only able to express itself at maximum efficiency when it is simultaneously stimulated on the one hand and restrained on the other. It is by the reins and the whip simultaneously that we drive the horse best. All reins or all whip would not do, but neither would the absence of both.

We must think of the lower centres as constantly receiving from the periphery and

from the higher centres myriads of impulses, impulses whose intensity varies from time to time, from hour to hour, with day and night and with waking and sleeping. Just as the hum of the traffic of the great city pours into your room when you open your window in the heart of London, so the neural hum of innumerable impulses pours into the central nervous system unceasingly so long as life lasts.

Let us now give a scheme embodying at one glance the various kinds of impulses which we have been studying in the preceding chapters.

I.—Musculo-motor:

1. To striated muscle:
   - tonic and voluntary impulses.
   - inhibitory impulses.
2. To non-striated muscle of hollow viscera:
   - viscero-augmentor (viscero-motor proper).
   - viscero-inhibitory.
3. To non-striated muscles of skin: pilo-motor.
4. To non-striated muscle of iris:
   - pupillo-constrictor (pupillo-motor).
   - pupillo-dilator (pupillo-inhibitory).

II.—Cardio-motor:
- Cardio-accelerator (cardio-augmentor).
- Cardio-inhibitory.

III.—Vaso-motor:
- vaso-constrictor.
- vaso-dilator.

IV.—Secreto-motor (glandulo-motor)	to sweat glands; sudo-motor.		
	to other glands	secreto-augmentor.	
		secreto-inhibitory.	

V.—To the electric organ (in fishes only); electro-motor.

VI.—To melanin-containing (pigment) cells; chromo-motor.

VII.—To any other tissues.

CHAPTER VII

THE MUTUAL CO-OPERATION OF NERVE-IMPULSES; INHIBITION; POSTURE

We have for the sake of clearness been studying the impulses and currents passing through the nervous system under conditions vastly simpler than those which actually exist. We have frequently considered only one reflex arc as being in activity at any given time, and as unrelated to neighbouring arcs or to currents descending from other centres. It need hardly be said that the actual state of affairs is inconceivably more complicated. Currents are constantly ascending by the afferent neurones of the posterior roots of the spinal nerves, and by the sensory nerves of the head, these are being poured upon centres for all sorts of functions; at these centres the impulses are met by other impulses which may be either augmentor or inhibitory from the higher regions, and as the result of all this neural congress, outgoing currents of due

strength, of altered rhythm, of suitable intensity are delivered to the various organs and tissues as tonic, augmentor or inhibitory, as the case may be.

It is now necessary to look into a number of conditions which present themselves for consideration in connection with the mutual behaviour of different sets of impulses which may happen to be travelling in closely related paths and centres. The conditions alluded to are such as facilitation, augmentation, interference, co-operation, inhibition, synergism, habit, the maintenance of posture and the part played by the cerebellum in the neural cosmos. We say "cosmos," because it is the opposite of chaos. Chaos is disorder, the observance of no law. There may be chaos in a city when a revolution is in progress; there is no control or authority, every one does what he likes, the strongest prevails, nothing is certain. Cosmos is the exact opposite of all this; the conduct of the government of a modern city or province is the civic or provincial cosmos, in a word, order. Now in the nervous system there is order in the normal state; nothing is chaotic. Impulses come in, impulses go out, and there is due correlation between them. Many and

powerful impulses may come in, a few, weak impulses may go out, or few and strong, or many and weak, or many and strong. The centres decide, to put it metaphorically, what kind of impulses are best for the body as a whole: there is order, method, mutual adaptation and co-operation for the common good. Order in motor activities is learnedly known as taxis or taxia, the opposite of which, ataxia or in-co-ordination is, perhaps, more often in one's thoughts. Co-ordination and in-co-ordination are, however, wider terms than taxis and ataxia. All sorts of things may be co-ordinated; muscular movements, nerve-impulses, ideas, theory and practice and so on, whereas taxis indicates order in muscular movements, ataxia disorder in them, that is, muscular in-co-ordination. The afferent nerves contribute to this cosmos quite as much as do the efferent, and this they do whether or not their impulses arouse consciousness. Were it not for afferent innervation, there would be no taxis in the efferent. If the heart could not send messages to the central nervous system to inform it as regards the excessive pressure opposed to its output, there would soon be cardiac chaos.

Suppose that impulses are, for the first

time, ascending an afferent neurone A; then theoretically these may pass to B or C or D or E, or any other possible contiguous efferent neurone. Owing either to some inherited or acquired disposition on the part of B to respond to the impulses arriving from A, the impulses pass to neurone B instead of to C or to D or to E. A second set of impulses arriving by A will now find a functional path to B, a path of lowered resistance, a path "canalised." There is now a functional connection (nexus) established between A and B; currents in A will tend to stimulate B more easily than they will any other neurone of possible linkage. Of course the A of our supposition means whole groups of A's, and our B means groups of B's. Take the case of an adult walking downstairs, carrying a tray, talking to some one in the hall below, and looking out of the staircase window. Such a person is not consciously, voluntarily, directing his feet and leg muscles to perform the movements of coming downstairs safely. He did originally; now all the A neurones concerned innervate all the B neurones involved, and the nett result is only duly co-ordinated (taxic) movements displaying "eumetria," that is, the requisite degree of force for the end in view. The A

impulses arise in skin, leg and feet muscles (in extero-ceptive and proprio-ceptive receptors), and the B impulses innervate the mutually co-operant or synergic muscles. The whole act is an example of a co-ordinated one, and one which, originally learned, to speak figuratively, by the spinal cord, is now almost entirely reflex, a complex co-ordinated series of reflex actions. There has been a high degree of facilitation through certain linked paths.

Synergism means that certain groups of muscles are associated together for a certain purpose. Occasionally we see what is apparently a meaningless synergism, as when a man is raising a weight, and his jaw muscles are clenched at the moment when his arms become active.

Suppose now, that a particular reflex action has possession of a path, say, the reflex for scratching the shoulder, a tremor of five to six a second in the spinal dog, then, if we stimulate the skin at some other point with a stimulation which under normal circumstances also brings out this particular reflex, the reflex in progress does not suffer any alteration in its rhythm, and is not complicated nor broken in upon. Possession is

nine points of the law of reflex action, as well as of other things. The reflex in possession of a path retains possession of it. Again, suppose that two receptors are simultaneously stimulated, the stimulation of each being such as to employ the same efferent limb of the reflex arc, but the one in a different way from the other, then either one or other reflex appears, but not the two together, there is no muscular compromise. Compromise might lead to confusion; in the lowlier life of the unconscious nervous system it does not occur: "one thing at a time and that done well," is another law of reflex action.

Part of the reason for this avoidance of neural compromise is that when a motor centre has started discharging into a synergic muscular mechanism, it exhibits a "refractory period" or period of insusceptibility (functional inertia), in virtue of which it becomes irresponsive to any other stimulation of an augmentor kind. This irresponsiveness or inertia towards such stimulation clearly makes for order in the nervous system and prevents confusion.

But that is not all; following many reflexes there is an after-period or refractory phase, in some of them as long as one second or

one and a half seconds, times in nervous activity of relatively great duration. Unquestionably this after-activity refractory phase allows of functional rest, of metabolic recuperation, short as it is. There is an analogous condition in the heart, a refractory period whereby it is prevented from receiving stimulation while it is in activity (systole). We see, then, that affectability is not the only property of living nerve-matter, there is the complementary property of functional inertia conferring an insusceptibility which preserves the living matter from exhaustion and from being the seat of compromise or confusion. Facilitation, then, is "use and wont," the effect of using the path sufficiently often. Paths once opened up in this way remain in functional linkage, it may be, for a very long time. The following is a good example of a sensori-muscular one; the old pensioner is crossing the pavement with his dinner on a plate; suddenly you call out in the voice of authority, "Attention"; he springs to the "Stand at attention" position, heels together and hands by his side, and, of course, down goes his dinner with a smash. The auditory receptors sent their transformed impulses into the well-worn path to hand

and leg muscles before any brain inhibition could be exercised. The sensori-motor reflex was too inevitable for the saving of the dinner. Facilitation in those centres which are the physical basis of memory explains the well-known fact that old persons, who cannot remember what happened yesterday, can remember perfectly what happened half a century ago. It is because that memory path has been so long used, is so well worn, that the physical traces in it are deeply engraved; and, on the side of consciousness, this means an unfading memory.

Once the resistance of paths is well worn down, the physical basis of habit is established. Facilitation explains how one plays better in the second game than in the first, say at tennis, and better in the third than in the second; it is the neural basis of "warming up."

Sometimes the expression "secondarily automatic action" is used for a habit or habitual reflex. The terms cover all those cases of sensori-muscular reflexes underlying posture and locomotion which have become almost excito-motor, so little is consciousness involved in them. But consciousness can be at any time directed to them; in certain cases it by no means helps the reflexes, and

may even interfere with them. This means that the spinal reflex mechanism is thoroughly facilitated and complete in itself, the consciousness aroused by the activity of the upward extension of the afferent neurone being now immaterial to the action, which is no longer in the tentative stage. A person may be able to walk downstairs in the dark, or to recite a poem, but as soon as he begins to think about the steps or the words respectively, there is often an interruption to the easy sequence of events, and he begins to stumble on the stairs or make mistakes in the recitation. Facilitation refers to the linking of paths, whereas augmentation refers to the increase in intensity or rate of rhythm of a reflex action. A good example of augmentation is as follows; if one observes the energy of the knee-jerk, the jerk of the leg produced when one leg is crossed over the other and the uppermost knee struck, one can notice a distinct increase in its energy a second time, if just before the knee is struck the person grasps his hands and presses them firmly together. The neural mechanism here is that impulses originated in the brain centres for the muscles of the hands are sent down on to the centre which is receiving impulses

from the blow on the knee to carry out the reflex jerk. As the result of the two sets of impulses simultaneously impinging on the spinal centre, there is augmentation or reinforcement of the lower by the higher, with the result that the jerk is increased if normal, and made obvious if previously imperceptible. One sensation may augment another thus: a small coloured patch not distinctly visible may become so when a tuning fork is brought near the ear: or place a finger in warm water, the temperature seems to rise if a red glass is held in front of the eyes.

The opposite of augmentation in neurology is inhibition. Although a strictly technical term, and one not used by the laity at all, it is not confined even by biologists to only one set of phenomena. The term is the equivalent of restraint, but it is as often used to mean depression, and by certain writers it is made even to include injury to a tissue or centre. As a term in neural physiology, inhibition indicates the bringing about of lessened activity, either in some peripheral tissue or in some nerve-centre through the agency of nerve-impulses. Inhibition exclusively at the periphery is certainly known only by experiment, as when we stimulate

the peripheral end of a cut nerve and observe some diminution of activity as the result. There are many such instances, the classical example being that of the heart (cardio-inhibition). Here we stimulate the lower end of one cut nerve—the vagus—with the result that the heart either beats very feebly or stops altogether in diastole. This is typical inhibition at the periphery, and was the earliest case to be discovered, namely, by the brothers E. H. and W. Weber, in 1845, at Leipzig. Since that time, nerves have been discovered which, when directly stimulated, relax intestinal muscle, muscle of iris, of blood-vessels, and other organs: these relaxations are peripheral inhibitions of tone. In other words, the stimulation of these various nerves induces the negative or resting, as opposed to the positive or active state in the tissues or organs. These experiments alone do not enable us to say that there are special nerve-fibres which convey nothing but inhibitory impulses, although this is in certain cases the fact; all they justify us in concluding is that impulses of a certain kind (intensity, rhythm, etc.), falling on certain tissues in a particular condition of physiological activity, diminish that activity or sub-

stitute the state of inactivity. A curious case of peripheral inhibition has been shown in the muscles of the crab's and lobster's pincers; under a particular kind of stimulation to the nerves, the pincer-muscle relaxes instead of contracting, thus opening instead of closing the "nippers." With regard to nerves to blood-vessels, slow stimuli cause inhibition (vaso-dilatation) while fast ones cause constriction. But the inhibition which more particularly interests us at present is central. The restraint of a neural process by neural means at a centre is true inhibition (Hemmung of the German writers), and this should be distinguished from the depression (Lähmung) of excitability of a centre by injury or damage to it, whether that be chemical (poisoning), or mechanical, such as concussion, or thermal (heatstroke). There is, of course, all the difference in the world between restraining a person from doing something and injuring him so that he is incapacitated from doing that thing. Only the former is physiological inhibition. After physiological inhibition, the activity ought to go on as efficiently as before, if not more so; clearly after injury the opposite would be true. And so we find it; after a period of inhibition the heart beats better

than before, it is stronger and fitter; after depression by cold or poisoning or mechanical injury, it is less fit for exertion. Restraint of activity in a healthy organism makes the organism as a whole fitter for future work; restraining a horse's activity makes him exceedingly fit for work, trotting, jumping, etc., when the restraint is removed.

Inhibition of a centre can only be by means of nerve-impulses; but these impulses may have had origin at quite different places in the body. They may, in the first instance, have had origin in the brain (cerebrum), in which case they may be either conscious or unconscious, or in the cerebellum, in which case they are always unconscious, or they may have had origin at the periphery, in which case the inhibiting impulses themselves are of a reflex nature. Let us take some examples, in the first instance, of conscious cerebral inhibition; this may be voluntary, ideational, emotional or sensorial. In plain language we may will to arrest a reflex or a tendency to reflex action. When our feet are being tickled we can restrain the tendency for the legs to jerk reflexly, we voluntarily inhibit the sensori-muscular reflexes. Or again, take the case of voluntary restraint of

the tendency to cough. Coughing is a pure reflex action (sensori-muscular), and yet we can restrain it, although a visit to some of our churches would seem to show that it is very difficult. Up to a certain point, we can restrain the tendency to cough, just as we can the tendency to jerk or wriggle when tickled, but beyond a certain point the inhibition is inefficient.

Laughing is an emotio-motor reflex action; we can often inhibit it when we see that to permit it would be unsuitable. But as we have already seen, the field of voluntary inhibition of reflex action is very limited; there is no such inhibition of a very large number of reflex actions denoted as excito-motor. In fact it may be said the lower the reflex the less it is under voluntary control; thus the reflexes connected with the sex organs, reflexes very old in the history of the race, are entirely outside voluntary interference.

From the active brain we have still to consider the ideational and emotional inhibitions. We know very well that an emotion may exert an inhibitory influence on medullary centres, as for instance, when shame produces the blush (inhibition of vaso-motor centre), when anxiety or fear dries the mouth

(inhibition of the centre for secretion of saliva), or when some mental state called "nervousness" quickens the pulse by inhibiting the cardio-inhibitory centre. Emotional and ideational states can depress tone and activity to an extraordinary degree: a piece of bad news is capable of converting a strong man into a toneless wreck. The well-known falling of the jaw and the general relaxation of muscles in disappointment is the result of inhibition of the tone of spinal cord and brain-stem centres through emotional or ideational states. Physiologically, in all those cases of voluntary, emotional or ideational inhibition, it is the cerebrum that is depressing the vitality of the reflex centres. Sometimes it may have been noticed that one is just about to sneeze, and one is suddenly informed of something very important, or one hears a sudden loud noise, in which cases the sneeze does not "come off," as people say. Here there has been ideational or emotional inhibition of an incipient sensori-muscular reflex action.

Inhibition can also be carried out through the activity of a sensory centre; thus a loud noise or a blinding light sometimes causes a person to drop something, or to slacken the hold of something.

If we speak to "the man at the wheel," his grip is less intense. An excellent example of sensory inhibition may be taken from the behaviour of two Canadian birds. Into certain lakes in Canada an osprey descends from a height with great dash, and fetches up fish with astounding skill. An eagle, watching this proceeding, waits until the osprey is flying off with his fish, the eagle then rushes at the osprey, making a noisy commotion, in the midst of which the bird loosens its hold of the fish, which the eagle immediately seizes. The strong stimulation of the osprey's centre for hearing inhibits the centres for the innervation of its leg and claw muscles.

But apart altogether from inhibitions due to conscious states, the brain exerts inhibiting influences of an unconscious order. The removal of the cerebrum (decapitation) in the lower animals results in a very striking increase in the ease of eliciting reflexes or in the intensity of the reflex action.

The spinal snake or other animal, if hung up by its head, makes incessant, rhythmical, swaying movements; a restlessness only to be accounted for on the assumption that by removing its brain, we have removed some unconscious inhibitory or restraining influence

upon the centres for the body. Cutting through the communicating paths between brain and cord has the same effect as removal of the brain.

Thus, in the spinal dog or cat, if one-half of the spinal cord be cut in the region of the neck, the reflexes behind this place on the same side are much more easily elicited than are those of the sound side. This shows that on the side of the severance, we have cut off the descent of restraining influences on the lower spinal centres. The scratch reflex, that is, hind leg brought up to shoulder, on the side of the severance is now elicited with ridiculous ease. Exactly the same thing is seen even in the invertebrates. Such decapitated animals are particularly restless; the posterior half of a divided worm wriggles more actively than the front half; the legs of the decapitated crayfish laid on its back, oscillate more rapidly than those of the intact animal similarly placed. A decapitated bee or wasp makes its legs oscillate at a greater rate than before. In the case of insects, the chief nerve-mass in the head acts like a brain in inhibiting centres farther back, but any such restraining influence must be quite unconsciously exerted. This unconscious cere-

bral restraint is an illustration of the hierarchy of centres, the higher governing the lower, the anterior the posterior, the later evolved, the earlier. As with many other things, we are aware of this restraint most when once it has been removed.

When the paths between the brain and the lower centres have been cut on one side, for instance, in a monkey, we find the limbs of the injured side in a fixed position known as "contracture"; they are bent and stiff, and have too much tone. The explanation is that the reflexes which maintain muscular tone in these limbs are too energetic in the absence of the unconscious restraint from the brain.

Now, in a sense we can restore this absent inhibition by artificially restoring the cerebral currents. Thus in a brainless frog, the intensity of whose spinal reflexes has been noted, if we stimulate in any way the upper part of the exposed brain-stem, we shall find that the reflexes, previously easily elicitable, are now feeble or suppressed altogether.

The inhibitory action of the cerebellum which is exerted on the cerebrum and not on the spinal cord, and which is not its only activity, we cannot enter upon at present.

The last region of origin of impulses which inhibit spinal and other mechanisms, is the periphery—either the skin or the internal organs (ecto- or ento-periphery).

In our discussion of the factors making for taxis, we found that a reflex action in progress, that is in possession of its arc, was not interfered with by currents which might at other times make use of the common path; this is not, however, the law for such reflex actions as have not yet commenced, that is, which are not in progress at all. We have, in fact, seen that they can be augmented; we are now about to see that they can be inhibited. For instance, the tendency to sneeze, a reflex respiratory action, can be inhibited by our pressing strongly on the upper lip. A bright light falling suddenly on the frog's retina, inhibits many of its reflex actions. Sometimes, instead of arresting the reflex, the reflex time may be prolonged; thus in the spinal frog, the reflex of removing the acid paper from the flank by the leg of that side has its time greatly lengthened by simply pinching the toes of the opposite side. Touching the tail of the decapitated crayfish, stops its leg movements; touching the skin of the spinal snake stops its swaying move-

ments; in all these cases the inhibiting currents have arisen at the periphery.

Before leaving the topic of inhibitions of peripheral origin, let us consider an interesting and typical case of such inhibition, which will serve for subsequent analysis, when we enquire into the possible nature of the way in which inhibition works.

Suppose we have a decerebrate frog whose heart-movements are being recorded, and whose intestines are exposed. If we give the intestines a sharp stroke with the flat of a paper-cutter, it will be noticed that the heart stops beating (experiment of Goltz). Physiologically this is a reflex inhibition of the heart by a reflex stimulation of the special medullary centre for inhibiting the heart. But, now, if when the heart has resumed beating, we pinch a toe at the moment that we strike the intestines, we shall see that the heart continues to beat, that is, it is not now inhibited. Physiologically this is reflex inhibition of a reflex tendency to stimulate an inhibitory centre, with the result that the centre is not stimulated, and therefore the heart not inhibited.

In bringing this chapter to a close, we may ask ourselves: Are all inhibitions of the

same kind, or are there differences in the ways in which neural restraint can be exercised? There seem to be differences.

In the first place, we must distinguish between inhibition at the periphery and inhibition of centres.

Peripheral inhibition need not detain us, because so little is known with certainty in regard to its mechanism. It is, at least, the induction of a state of lowered tone in place of higher tone; in muscle, relaxation is substituted for contraction; in heart, diastole for systole; in blood-vessels, elongation for contraction of circular fibres; and in glands a state the opposite of secretory activity. But how exactly nerve-impulses effect those changes in the nutritional states of tissues is by no means certain.

But as regards inhibition at or of centres, we seem to be able to be a little more definite. As types for analysis we may take: Voluntary inhibition, ideational, emotional or sensorial; and lastly, reflex, or by currents of peripheral origin.

In voluntary inhibition, we have currents from the brain descending on to centres in which incipient processes for the performance of reflex actions are in existence, *e.g.*, jerking

of muscles or coughing. It may be that the voluntary impulses interfere with the reflex-causing impulses, after the manner of sound-waves interfering to produce silence, and light-waves interfering to produce darkness.

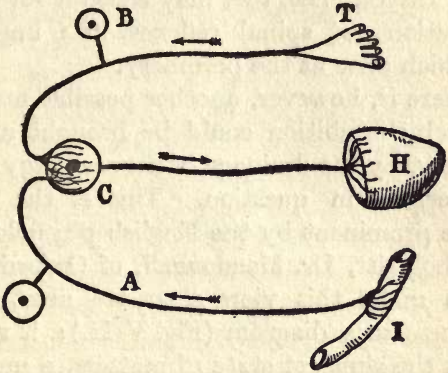

FIG. VII.—C is inhibitory centre for heart, H. T, toes. I, intestine. Impulses over A tend to stimulate C; impulses over B tend to inhibit those at C; therefore C is left alone, that is, it is not stimulated.

There are, at any rate, good analogies in the physical world to warrant our explaining inhibitions of this sort on the theory of interference. This kind of explanation also accords with the idea of nerve-force as a reality, a subject which we shall discuss in Chapter IX.

The cerebral impulses here would be purely inhibitory or anti-motor, that is of a quelling or restraining nature. Interference explains very well such a phenomenon as repression of sneezing by strong pressure on the upper lip. Interference, too, may account for these inhibitions of spinal reflexes, the impulses of which arise at the periphery.

There is, however, another possible method whereby inhibition could be brought about, namely, by the drainage of nerve-energy from the centre in question. This is the view made prominent by the English physiological psychologist, Dr. Macdougall, of Oxford.

To make this view clear we must have recourse to a diagram (Fig. VIII.); it represents the simplest state of matters, a muscle-group and its antagonist. When all is at rest, it is supposed that the neurone X innervates E, but that an offshoot x_1, a collateral from X goes to B, and a similar one, y_1 to A. A and B are centres for the extensors and flexors respectively. Now if Y innervates the flexor group in order to bend the joint, then by overcoming the resistance at B, it forces a path across B to F, and so lowers the resistance of B. But the lowering of the resistance at B will have had the effect of

opening up a path for the nerve-energy of the neurone X by a path of less resistance than A to E affords, therefore *some* nerve-energy is drained off into B by x_1 or leaks over by x_1, and so the relative intensity of the innervation at A is reduced, that is, A is inhibited.

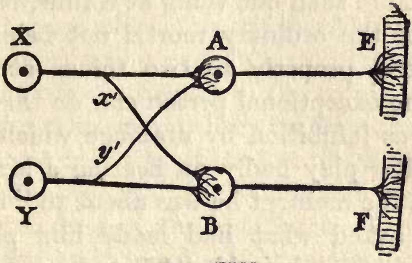

Fig. VIII.

This inhibition by drainage is, in the sphere of consciousness, inhibition by withdrawal of attention; we know well that if our attention is withdrawn from anything we are doing, then we do that thing with very much reduced intensity or not at all. Drainage in the sensory sphere explains the diminution in innervation of the hand-muscles of the steersman when you "speak to the man at the wheel," nerve-energy is drained off into his auditory centres, and from those for his muscles, which, therefore, contract less accurately with less

synergism and eumetria. Similarly when the osprey let go the fish, its centres for muscles were inhibited by drainage of nerve-energy into its auditory centres stirred up by the noise made by the eagle. Inhibition by drainage is the mechanism of our inability to do more than one thing at a time, it is the basis of the ordinary mortal not being able to attend properly to two things at once; only the exceptional person can do this.

It was inhibition by drainage which made the golfer play badly on hearing a lark sing just at the moment he was about to "drive." When asked what had made him play so badly, he simply said, "That d——d lark."

Inhibition by drainage explains satisfactorily some of the facts of the hypnotic trance, namely, those where we have high sensitiveness of one sensory centre coupled with great insensitiveness of the others or of one in particular. Thus, if the visual centres have been made hypersensitive (by processes which do not now concern us), then we shall find that the centres for touch and pain are quite insensitive, the excessive innervation in the former centres has by drainage inhibited the latter. A person so hypnotised can see many things the normal person cannot, when at the

same time he is unaware of contacts and quite insensitive to such pains as those of teeth extraction and other minor operations. Psychologically it is withdrawal of attention, neurally, it is inhibition by withdrawal of nerve-energy; it is inhibiting by extreme degree of forgetting.

Had space allowed us, we should have taken up the interesting and difficult subject of the place of the cerebellum in the neural cosmos. Briefly it is an organ which, on the unconscious plane, not only inhibits but at times augments the intensity of the innervation from the motor centres of the cerebrum. It is often described as a co-ordinating centre; it would be better described as a corrective organ, at one time reinforcing, at another restraining the output of nerve-energy from the highest brain-centres which attend to the body muscles. In this way it is involved in the maintenance of equilibrium of the body, whether at rest or in motion. The cerebellum innervates posture and locomotion on the unconscious side.

CHAPTER VIII

FATIGUE AND REPAIR OF THE NERVOUS SYSTEM; SLEEP

ONE of the most "familiar experiences" in life is the feeling of fatigue. At one time we feel fresh or "fit," as the present-day slang is; at another we feel tired, done up, fatigued, and we know that this condition may go on to one called exhaustion. Now these things concern only our sensations, what the learned would call subjective fatigue. But experimental work has revealed to us some facts as to what fatigue is outside of our sensations, fatigue objectively considered.

It is these, first of all, that we should look into, because we are likely to get information of a positive kind, altogether unconnected with our own feelings or impressions; objective facts about fatigue. Let us first investigate the motor neurone and its associated muscle as we may have them dissected

out of a frog. If we stimulate electrically the motor nerve to a muscle arranged for recording its contractions, we shall find that, after the first few contractions, each one of which is better (higher) than the preceding up to a maximum, the contractions begin to fall off in height by equal decrements and finally die away. If now at this moment when the muscle contracts no more from stimuli sent into its nerve, we stimulate the muscle-fibres themselves (direct stimulation), we shall find that the muscle *does* contract again, not with its original energy, but still in a manner to show that it is not the chief seat of the fatigue. We saw in an early chapter that the fatigue of nerve-trunks was very slight, and indeed, had only been discovered after much laborious research. If, then, the chief seat of the fatigue is not in the muscle-fibres and not in the nerve-trunks, it can only be in some structure intervening between the two, at the neuro-muscular junction. Now there is at this place a very specialised portion of nerve tissue to which we have not yet alluded, known as "the motor end-plate." The word "plate" is highly misleading, for the region in question consists of a bed or cushion of granular

protoplasm over which are distributed nerve-fibrils of great delicacy. This arborescence is, in fact, the termination of the efferent musculo-motor neurone. We shall see presently what it is that fatigues this neuro-muscular junction; let us note in the meantime that this is functionally the weakest link in the neuro-muscular chain. We do not in the least mean to say that there is no such thing as real fatigue of muscular substance, but what we have learnt is that the place at which the conduction is least good, that is, at which the resistance becomes highest soonest is where the nerve ends in a brush of fibrils over the muscle.

But an isolated muscle, whose nerve has been cut and has died, can, of course, show fatigue. The contractions here do not fall off so regularly as in neuro-muscular fatigue, but rather fast at first and more slowly later. There is such a thing as fatigue of muscular fibres, as all athletes know, and it is associated with a more sluggish action and with increasing stiffness. The chemistry of the subject of muscular fatigue has been a good deal worked at in recent years, and we now know something of the substances manufactured by the active muscles and poured into the

blood, substances of a more or less poisonous nature, and therefore conveniently called fatigue-toxins. Besides carbonic acid gas and an acid, lactic, there are probably substances of more complex, organic nature which are responsible for the falling off in capacity of the neuro-muscular junctions, and of the muscle-fibres, and for sensations of lassitude which we have already called subjective fatigue. In fact, our experiences in fatigue and in some mild case of general poisoning are very similar ; there is the same disinclination to exert oneself, the sleepiness, the slight fever, the headache, the same feeling of general unfitness for any emergency or crisis. The stiffness of over-exercised muscles is due to a change in their viscous substance brought about by the presence of the acid already alluded to. Athletes know that a warm bath and massage to some extent dispel this fatigue ; the physiology of the process being that the increased blood-flow through the now resting muscles washes away the acid stuff. It was demonstrated years ago that, if one fatigued a dog, killed it at once and injected its blood into the veins of a normal dog this animal showed all the signs of fatigue which a dog usually shows.

We may take it as proved that muscular fatigue objectively on its chemical side consists in the manufacture by the muscles of certain soluble substances which, entering the circulation, depress activities after the manner of soluble poisons.

But, clearly, all fatigue is not of muscles; there is a fatigue of nerve-centres: this may be studied, or rather glimpses of it may be got in the following ways:—

(1) We may study neural fatigue on its chemical side; the problem of the chemical results of the activity of the brain and central nervous system;

(2) we may study the microscopic aspect of the question, the problem of possible minute changes in the nerve-cells as the result of prolonged activity;

(3) we may try to find out the exact seat of fatigue in prolonged, volitional, muscular effort;

(4) and, lastly, there is the subjective side; true mental fatigue—the correlate in consciousness of brain fatigue.

On the chemical side, the information is not full, but such as it is, it is in line with what we know of fatigue elsewhere. We find chemical evidences of activity in nerve-cells; an

acid reaction has been demonstrated after prolonged activity.

We well know that we can become fatigued after the nervous system has been continuously active for some time ; thinking out problems, sight-seeing, following an abstruse dissertation perhaps in a foreign language, worrying over something, or experiencing powerful emotions. We talk, and rightly, of some subject of thought as fatiguing ; some people find listening to certain plays or pieces of music very tiring. It is absolutely certain that violent emotions, whether of joy or grief, are fatigue-producing. There is undoubtedly such a thing as pure mental fatigue quite apart from what is called being "bored." There is an intellectual, emotional and sensory fatigue. A certain public lecturer says that he feels as tired out after merely standing talking for an hour, as though he had walked ten miles.

In an extreme degree there is "brain fag" from over-work, a real thing for which the preacher, actor, financier, or prime minister needs a complete rest ; the physical basis of this is objective fatigue of the cerebral cells.

These facts are now being recognised in connection with the hygiene of school children. Their fatigue is primarily neural, but if you

keep them standing on their feet while "doing" lessons, you add muscular fatigue to the mental.

Nerve-centres, then, are fatigueable; but we may ask the question, how does the time of the onset of their fatigue compare with that of neuro-muscular fatigue. To investigate this, we must return to our efferent neurone and muscle, this time intact, and in ourselves, not isolated from the nervous system.

There is an instrument called the ergograph, whereby we can register the heights of our voluntary contractions, and that without necessarily observing the results. We select, say, the flexor muscle of the middle finger of the right hand; and at certain equal intervals of time, contract this muscle by the efforts of our will. After the preliminary improvement always noticed, the twitches are slow to show diminution, but by degrees, fatigue sets in, and decrease in height of contractions can be observed. In the end, full fatigue comes on, and we feel we cannot make the muscles twitch any more, although we are perfectly conscious that we are still willing to twitch them, we are not mentally tired out, but our volitions are ineffective; the muscles won't work in spite of our will. If now at

this instant, electric stimulation be applied to the skin over the nerve for this flexor muscle, the muscle contracts, and if the muscle itself be stimulated through the skin, the muscle contracts.

We, therefore, conclude, that as regards normal, volitional impulses, the earliest seat of fatigue is again the neuro-muscular junction. Though this delicate junction is the spot where fatigue first occurs, yet we are conscious that we are not quite so fresh as we were at the beginning, that, in fact, there is a disinclination to do much more. We have to force ourselves to do any more, and at last, as the combined result of distress or actual pain in the arm-muscles and the feeling of disinclination to do any more, we stop working. Unquestionably there is at this time fatigue of the brain motor centres, but in point of time end-plate fatigue came first.

The order of onset of fatigue is, then (1) the end-plates; (2) the centres; (3) the muscles.

In the early vulnerability of the neuro-muscular junction, some have seen a protective mechanism against full exhaustion of the muscle, for if the brain is still fresh enough to go on willing to contract, and if the muscle itself is still capable of contracting, then it

would be possible to bring on exhaustion in the muscles with very much greater ease than in actual fact. By extraordinary volitional efforts, the great resistance at the end-plates *can* be overcome, and central and muscular exhaustion is then a possibility. The classical example is, of course, that of the man who ran from the battlefield of Marathon to Athens to announce the victory of the Greeks over the Persians. He ran more than twenty miles without stopping, and on arriving at his destination fell down in the exhaustion of death. Similar cases have occurred from time to time. People have rushed from a maniac or from a wild animal, or from a forest fire, and have fallen down dead from total exhaustion of muscles and centres. Normally, however, this accident is prevented by the resistance rising so greatly at the end-plates; Nature's fuse has blown at last.

But, in truth, central fatigue is not equally easy to produce in all centres of the nervous system. Sensory centres can be permanently fatigued, as when loud, long continued noises fall on the ear, for instance in boiler-makers' deafness; here the centre for hearing having been over-stimulated is paralysed, permanently fatigued; but in conditions of health a high

degree of fatigue is never seen in the centres of the brain-stem and cord. In fact, the tirelessness of certain centres is very noteworthy. Think of the centres for breathing, for the heart, for the blood-vessels, for the tone of muscles; under all ordinary circumstances these centres never tire, never cease working.

The probable explanation of this is that they work on the principle of a rhythm, not incessantly, but with intervals of rest or reduced activity. Rhythm is really one of Nature's mechanisms for preventing fatigue.

We must, however, remember that fatigue is a relative state of matters. After a hard day's work, a man may call himself fatigued, and be glad to lie down and rest; but suppose he is suddenly told that the house is on fire, he can jump up and dash off to save his family or valuables. He can overcome his fatigue under a sufficiently urgent stimulus. Fatigue is, then, a state of diminished functional fitness for future activity, the degree or the extent of the diminution depending on the previous state of fitness of the centre in question, and on its reserve powers, and on the resistances it has to overcome in order to do any further work. What would fatigue A may leave

B unaffected; whereas A needs a rest of hours to be refreshed, B needs only a few minutes.

Certain centres show some degree of fatigue in a rhythmic manner during the twenty-four hours; and of course the nervous system as a whole does so, our falling asleep being the familiar correlate on the conscious side. Such a centre as the vaso-motor, for instance, shows relative fatigue in the course of the twenty-four hours. It is freshest in the morning, as the day wears on it innervates slightly less and less intensely, until in the late evening it has not got anything like the hold on the vessels which it had earlier in the day; certain parts swell a little, and collars and rings are known to be tighter towards night.

It is undoubtedly by its possession of rhythmicality that the respiratory centre continues so unfailingly to put forth its impulses as long as life lasts. Surveying centres from the broad functional standpoint, it is those least associated with consciousness which show the least fatigue. Centres concerned with sensorial registration, memory, volition can all show fatigue, whereas it would be scarcely accurate to say that the centres for perspiration, vomiting, for the heart, or

for saliva ever exhibit more than the most fleeting degree of functional disability.

Yet if by fatigue we mean increase of resistance in any synapsis, then such a condition may, from more than one cause, become established in any centre at any time. We have good grounds for holding that one factor in central fatigue is the increase of this central resistance, for the rise in resistance at the neuro-muscular junction is fatigue of the peripheral neurone. The cause of this increase of resistance is chemical, it is of the nature of a poisoning. The present theory is that the fatigue-toxins, bathing the delicate fibrils at the end-plates, or the delicate tendrils at a central synapsis, cause these to retract, just as the tentacles of a sea-anemone retract when poison has been stirred up in the water of the tank.

It needs no physiological knowledge to understand that in sleep we recover best from fatigue, that we must have sleep in order to live. But few persons, if questioned, could say exactly what are the causes of sleep, the conditions predisposing to it. It is often the most familiar that is the least understood. Most people know sleep as the great restorer, but how?

The first thing that may be remarked is that normal sleep will not come on unless the person is fatigued, not unduly but healthily. Very few persons can go off to sleep to order, irrespective of whether they are tired or not. A great deal has been made of the normal rhythm of sleep; and it is perfectly true that in most people some sort of periodicity as regards sleep comes to be induced. If a person is accustomed to go to bed at eleven at night, he will begin to feel sleepy about that time. The establishment of this rhythm or habit of sleep is an excellent thing, a most valuable thing to those possessing it, difficult to re-acquire by those who have lost it. On the speculative side we may connect this rhythm with the great cosmic and vital rhythms around us, the rising and setting of the sun, the ebb and flow of the tide, the opening and shutting of the flowers, the periodicity in the heart's action, and so on. Most animals with a nervous system rest from time to time, even when they do not lose consciousness. The more lowly the nervous system of the animal, the less truly does it sleep; the fish, for instance, can hardly be said to sleep. The case is recorded of a boy in Nuremberg whose life had been "spent

in absolute solitude, having no knowledge of men, animals or plants." He always went to sleep as soon as the sun had set. The brain of the higher mammals, like so many other organs, has a functional rhythm; it is not continuously in full activity, it works, it rests. When it works, we are conscious, when it rests completely, we are unconscious; a dream is, physically, the partial activity of an otherwise resting sensory centre; psychically it is the arousing of a particular kind of consciousness related to the centre or centres in question. It seems that in normal conditions, the adult brain requires to rest absolutely seven to eight hours out of the twenty-four. It would seem that normally one cannot resist the effects of fatigue for more than about eighteen hours; of course exceptional people may, under special circumstances do this, but not the average person. Fatigue, whatever it is, is removed during sleep, and completely only during sleep. Now as a certain amount of fatigue is inevitable, if physical or mental work is to be done, and as fatigue cannot be entirely removed except in sleep, it is clear that unless fatigue is to go from bad to worse, sleep is an absolute necessity.

Sleep is as necessary as food, indeed deprivation of sleep can be withstood even with greater difficulty than deprivation of food. A Russian physiologist kept some puppies awake for five days, at the end of which time they died, although they were taking food; whereas the controls which were allowed to sleep as much as they liked, but from which food was entirely withheld, survived to the twentieth day, and were saved by being cautiously fed. A sleepless animal at the end of three to four days is as miserable as a starved one at the end of ten to fifteen. A certain amount of sleep is equivalent to a certain amount of food. People who sleep on past breakfast are often not particularly hungry when they awake, and are quite pleased to wait till lunchtime. In loss of sleep the brain never gets any rest; it is too delicate a mechanism to work continuously. A watch is a very delicate mechanism, yet it does not become fatigued; fatigue is one of the differences between the living and the non-living. Sleep, then, is necessary to remove fatigue, but that does not tell us what it is that induces sleep. We ought to be prepared to find that there is no one all-prevailing cause of sleep, but that several co-operant conditions predispose to it.

It seems that perhaps four conditions co-operate in bringing about sleep, but almost certainly not all four with equal potency on each occasion that sleep is induced.

These conditions are—

1. The presence of fatigue products in the blood;
2. The absence of sensations;
3. The state of the circulation in the brain;
4. The absence of mental activity.

We may thus speak of a chemical, a sensory, a vascular, and a psychic type of sleep. It is possible that in different people, a different factor predominates at any one time as the chief cause of sleepiness. We have good reason to believe that the presence of fatigue-toxins in the blood is to increase the resistance at synapses. The result of this rise of resistance at the synapses where the afferent neurones enter the sensory centre, is to cut off from these centres impulses from the periphery. On the mental side of things, this means that in proportion as impulses do not reach these centres, consciousness related to the centres will vanish. If the centres are not stimulated they will cease to be active; they go into functional rest, that is, they sleep.

This is the chemical or toxin factor in the

onset of sleep; the active tissues, both muscular and nervous, have manufactured during the period of wakefulness more or less of these toxins, and their influence on synapses within the sensory centres is to raise the resistance to such a degree that impressions from the outer world or from the bodily organs cannot gain access to the centres. The centres are in perfect sleep, inasmuch as they are unconscious of external or internal things, and not being aroused to partial activity are not dreaming. Thus, in reality, factors one and two are closely associated; owing to increase of resistance at sensory synapses, sensory impulses are cut off from the sensory centres and therefore sensations are no longer, for the time being, perceived. Factor two is absence of sensations, and we see how it follows from factor one. But, of course, when desiring to go to sleep, we take care to cut off all sources of sensations; we *make* factors two and one co-operate. We get off to sleep best when we retire into the darkness and exclude the sounds of the outer world. Yet under certain circumstances, provided the fatigue is sufficiently great, we can sleep in the midst of intense sensory stimulation. In fact chemically induced sleep, the sleep of

the toxæmia of fatigue, is quite irresistible. A great accumulation of fatigue toxins produces sleep under all circumstances. As one writer has well put it, "We suffocate our cells with the ashes of our waking fires." Many of the camel-drivers in Lord Kitchener's forced march to Khartoum fell from their seats in sheer exhaustion, and slept then and there on the sand while the army corps thundered past. Utterly exhausted gunners, in the days of the old muzzle-loading cannon on "the wooden walls," have fallen asleep and remained asleep a few feet from the gun continuing the bombardment. In the old coaching days, postillions often fell asleep on horse-back, and yet kept their place in the saddle. Sentries have fallen asleep at their posts in utter exhaustion, and have retained their erect posture. Readers of De Quincey may remember that his "Vision of Sudden Death" was written after he had been driven at thirteen miles an hour by a driver fast asleep on the box of a mail-coach. More than once the cross-Channel swimmer Holbein has been noticed by the men in the boat to be asleep though still swimming. This is a very instructive case for analysis; the synapses in the sensory brain centres were fully fatigued,

and the isolated centres consequently went to sleep, but the toxins had not similarly disabled the centres of the spinal cord, for through them were carried out the co-ordinated reflex actions which constitute swimming. The spinal cord does not, therefore, sleep in the sense that the brain does ; as it is not related to consciousness, so neither does it suffer in its reactions when consciousness is abolished. Spinal synapses have a higher degree of functional inertia towards fatigue-toxins than have those of the cerebrum. A colonel of volunteers, well known to the author, told him that after going through twenty-two hours of extreme fatigue both of body and mind in connection with the Review of Scottish Volunteers held at Edinburgh in 1881, he walked in his sleep in the dark for several miles along a coast road in Scotland. That acute observer, Mr. Rudyard Kipling, has not failed to notice cases of sleep due to extreme fatigue. In *Stalkey and Co.* he says, "After that I went to sleep; you can, you know, on the march when your legs get properly numbed. Mac swears we all marched into camp snoring, and dropped where we halted." Extreme sensory stimulation or the endurance of long continued pain finally

brings on sleep. In "the good old days" of torture, victims used to fall asleep on the rack. Cases have again and again been recorded of persons falling asleep when bound to the stake before being burned alive. A vivid instance of sleep after prolonged bullying which, psychologically, is the combination of physical and mental pain, is also to be found in *Stalkey and Co.* "When Fairbairn had attended to me for an hour or so, I used to go bung off to sleep on a form sometimes." Here toxins both of muscular and of neural origin so raised the synaptic resistances in the sensory centres that the further passage of impulses over them was prevented as by a self-preserving mechanism. Were something of this sort not to occur, then there would be nothing to prevent the fatigue-toxins permanently damaging the sensory centres.

As far as we have gone, we see that sleep is the result of a certain kind of poisoning of brain-cells coupled with the diminution of sensations. Now it is rather interesting to find that there is a type of sleeplessness corresponding to each of these sleep-producing factors. If the toxins of fatigue have an irritant instead of a soporific action on the brain-cells, then we shall have that form of

sleeplessness, quite a well-known one, where a person is "too tired" to sleep. Athletes have it, and children often complain of it. Possibly here part of the sleeplessness is due to pain or discomfort arising in the over-exercised muscles, tendons or ligaments. The part played by sensations as sleep-producing is, therefore, a negative one. Under ordinary circumstances the presence of sensations keeps centres awake, although very long continued sensations produce fatigue, and in that way bring on sleep simply by being the causes of the production of neural toxins. There is most certainly, however, a sensory insomnia; lights, noises, pain, heat or cold can all keep us awake. Being too hot in bed, having one's feet cold, the presence of an aching tooth, are all familiar examples of sensory causes of sleeplessness.

Whether or not sensations will keep us awake, is a matter depending on how much our attention is engaged with them. Long-continued, but not actually fatiguing, sensory impressions—droning preaching or reading aloud—permit of sleep, because by the mere monotony of the sensations they cease to engage our attention at all. Any persistent not too vivid sensation—contact of our

clothes, of the atmosphere, etc.—ceases in time to be for us a conscious sensation at all. This principle of the relativity of sensations is an interesting one. It explains how under certain circumstances the actual *absence* of a sensation can keep one awake. If a person has become accustomed to sleep in the noise of a great city, then he finds it difficult to sleep in the quiet of the country. This is, of course, because his attention has been arrested by the relative change from noise to silence. Strictly speaking, this cause of sleeplessness is related to the psychic factor mentioned last on the list.

The third factor in the inducing of sleep is the diminution of the energy of the circulation of the blood through the brain. A general knowledge of physiology would lead us to expect that if an organ is to pass into a state of functional rest, its blood-supply would undergo diminution, for it is an axiom in physiology that the more blood, the more activity. The proofs that there is less blood in the skull and brain during sleep are both direct and indirect.

Let us look first at some of the former. In more than one case of head injury, where the brain has been exposed by the removal

of a piece of the skull, it has been noticed by direct inspection that the brain-substance is paler during sleep than in the waking state. Similar observations have been made on the brains of dogs which were specially operated on. In one case a piece of bone was removed, and a glass window inserted into the hole; when the animal slept the brain was seen to become distinctly paler.

In very young infants there is a spot on the top of the head (anterior fontanelle), where only skin and membrane, instead of bone, cover the brain. It pulsates quite obviously with the heart-beat. If this membrane be watched when the child falls asleep, it will be noticed to sink in. This would indicate less substance in the child's skull; now the only material that can vary in quantity there is the blood, therefore there is less blood in the child's brain during sleep. Conversely, when the child cries or is in a rage, this fontanelle bulges out, indicating that there is now more blood than before in the brain.

More indirect still are the inferences from observations on the re-distribution of blood in the body during sleep. The argument is, you take a record of the volume of some

part, say, the hand or arm before sleep, and then during sleep, and if you find that the part in question has swollen during sleep, you conclude that, as now there is more blood in it, there must be less in the brain.

If the hand is thus studied, it is found that it does swell in sleep ; in fact, there is more blood altogether in the skin than there was before ; the blood shows pink in people of fine, white skins, hence the expression " sleeping beauty." Since the quantity of blood in the body is, during the time of such an observation, constant, it is clear that if more blood has gone to any part, there must be less of it in the brain.

Perhaps one of the most striking ways of demonstrating the relative distribution of blood in sleep, is the method which we owe to the late Professor Mosso, of Turin. A man on his back is accurately balanced on a board supported in the middle like a see-saw. He is then allowed to go to sleep. As he does so, the end of the board where his feet are is seen to dip down, and, of course, the head-end to rise. The only cause of this must be that now more blood is in the legs and feet, and less in the head ; there has been a re-distribution. Falling asleep after a meal, is explained

by the fact that the blood has been re-distributed; more being needed by the digestive organs means less available for the brain, and the cutting off of the blood means cerebral rest, which means unconsciousness.

Old people with feeble hearts are apt to fall asleep when in a sitting posture owing to the ease with which the blood in that position leaves the brain. This was so in the case of Her Majesty the late Queen Victoria. During the last few months of her life she would frequently be found to have been asleep in the carriage on her afternoon drive. The ease with which people fall asleep in the Turkish bath, is due to the relatively large amount of blood in the dilated vessels of the skin, and therefore corresponding diminution in the brain.

Now there is an insomnia from too energetic a circulation of blood through the brain. If the heart is beating too fast or too strongly as from exercise, or from the warmth of a very hot bath, or from emotional excitement, then the blood is rushed through the vessels of the brain and most effectually keeps that organ awake. There is, then, a vascular insomnia as there is a chemical and a sensory.

Finally, the absence of mental occupation is

conducive to sleep. This is very well known to all. Everybody knows that anything on the mind,—grief, joy, or a mathematical problem—will prevent sleep. As long as the mind is obsessed, so long is sleep impossible; unconsciousness is incompatible with vigorous brain activity.

There is, therefore, a psychic insomnia, possibly one of the most difficult kinds to overcome. This is, of course, the type to which the author of "King Henry IV." referred in the very well known lines :—

> "Sleep, O! gentle sleep,
> Nature's soft Nurse, how have I frighted thee;
> That thou no more wilt weigh my eyelids down,
> And steep my senses in forgetfulness."

A worthy old Scottish minister was once asked how it was he contrived to sleep so well; he replied: "I resolutely refuse to be worried with anything after ten p.m."

No doubt the mental factor co-operates with other sources of sleeplessness, the vascular, for instance. Thus the mind will be very much awake after experiencing an unusually vivid series of sensations, and the heart at this time will be found to be in exaggerated action. After the children have come back from the menagerie or the pantomime they

cannot sleep. According as there is increased blood-flow through the brain, from any cause, there will be increased flow of ideas through the mind, and so long as there is, sleep is difficult or impossible. Increased blood-flow induces ideas; thus conversation is so much better after exercise than before.

Sleep then, is, the resting-time of consciousness, and as truly the resting-time of the central nervous system. Although the spinal cord does not become unconscious, for the excellent reason that it never was conscious, yet it would be a great mistake to suppose that it does not rest. It rests as completely as it can, compatibly with its maintaining some degree of tone in the muscles and in the internal organs innervated by it. That there is a distinct diminution of tone in the muscles is evidence that the cord is innervating less vigorously; it is resting. The whole brain-stem is resting; thus the pupil dilates in sleep, for the innervation from its centre is less intense.

CHAPTER IX

THE REALITY OF NERVE FORCE, NEURIN; POTENTIAL; NERVOUSNESS

It has often happened that what the public, the non-scientific laity, most firmly believe in, has been found under the scrutiny of scientific analysis to have no foundation.

That the moon influences the weather, that it is unlucky to be married in May, that hanging a horse-shoe on the door brings good luck, are examples of beliefs which have arisen from an insufficient grasping of the notion of cause and effect. One of the beliefs firmest in the public mind is that there is such a thing as nerve-force. The ordinary man writes and speaks about nerve-energy, a strong or a weak nervous system, nerve tension and so on, and he believes in nerve-force as literally as he believes in heat or light or electricity.

Until comparatively lately, academic physiology took no cognisance of this; even

now " nerve-force " has no place in the text-books. The time is well within our memory when in a purely scientific circle to have talked of nerve-force would have been to raise that peculiar kind of smile which indicates that your hearers—quite superior people—regard you as not far removed from a quack or a dupe. Nerve-energy was good enough for ordinary or drawing-room use; but it was not " scientific " in the sense that the terms muscular energy or the potential energy of food were. Academic physiology had heard the term nerve-energy, but it did not use it; it left it to the manufacturers of magnetic belts, or electric boot-soles and to other opulent charlatans who flourish greatly on the soil of the popular ignorance of physiology, vast deposits of which are to be found both in England and America. The popular novel would lose much of its interest if that forceful character with the magnetic presence, the dark, deep, penetrating eyes, and the long, thin, nervous fingers were dethroned.

To the plain man, the indications that the nervous system is force-producing (dynamogenic) are clear enough. We can rouse resting muscles to activity or we can quell incipient activity, and the one requires energy as much

as the other. He sees that we can exert little or much effort according as the occasion demands. We can, in particular, not only resist fatigue which we feel to be coming on, but when a high degree of it has been established we can overcome it under exceptionally great stimulation. The tired-out man *can* put forth a supreme effort to escape from the burning building, or the exhausted mother to save her child from drowning. Under exceptional circumstances exceptional efforts can be made; nerve-energy, therefore, would seem to be a real thing, as real as the energy of the heart-beat or of the blood-pressure. What one might call the classical case of this is the conduct of Colonel Baird Smith in the Sepoy Mutiny. He conducted the siege operations before Delhi; for months he hardly ate or slept, but worked at extreme pressure without showing fatigue. When the end came, he collapsed,—an emaciated, inert, almost lifeless invalid.

But, further, nerve-force in the abnormal may be appealed to. In mania, there is an exhibition of force through the muscles which may be alarming or positively dangerous, according to circumstances. The maniac can perform feats of strength absolutely astonish-

ing to those who have never previously seen this sort of thing. The force is exhibited by muscles, but they are forcefully innervated. Feeble innervation will bring out feeble action; stronger, stronger; while maximal innervation will bring out maximal muscular effort. Behind the muscular energy, there must be nerve-energy, the former being called forth by the latter: the latter must, therefore, be a reality. The surprising development of muscular power displayed by a person in the cataleptic state of the hypnotic trance must be due to an antecedent power in the nervous system. Were the nervous system not capable of putting out energy, this condition could not exist.

Take the converse of this, the state of the nervous system in acute melancholia. Here, for reasons we need not enter into, the nervous system is supremely depressed; it can hardly be got to put forth any exertion at all. Atony and asthenia are its features. The muscles, feebly innervated, are toneless, flabby and capable of very little effort. Not only they, but all other tissues are poorly innervated, blood-vessels, glands, skin and the internal organs. The heart is soft, slow and feeble, the digestion poor and weak

(atonic dyspepsia). But all this deficient tone is due to antecedent deficient innervation, therefore nerve-energy must have an objective existence.

Now, whereas the physiologists have been irritatingly slow to bring the conception of nerve-energy into their scheme of the working of the nervous system, the more thoughtful physicians have for some time been using both the term and the conception in dealing with neural problems brought under their notice almost daily. Dr. Hale White was the first English writer formally to enunciate the doctrine of the objective reality of nerve-force, which he did as far back as 1886, when he coined the term "neuro-rheuma," or flow in a nerve. Sir Victor Horsley and Dr. Sharkey have concurred in this teaching. Amongst English physiological psychologists, Dr. MacDougall is one who has frankly faced this problem both of the existence and source of nerve-energy, and has set forth his views in a luminous fashion. On this subject he wrote in 1908, "another conception of the whole operation of nervous energy which goes back as far as Descartes; the conception namely, that the energy liberated by chemical change, by katabolic

process in one part of the nervous system may be conducted through the nervous channels and may operate in other parts of the nervous system. . . . Now it seems impossible to get the physiologists of the laboratory . . . who are chiefly concerned with the organs rather than with the organism, to consider this conception seriously, and on its merits. If they occasionally refer to it, it is only to put it aside contemptuously as a naïve survival from the Dark Ages. Yet those who are in the habit of dealing with the problems of the organism as a whole, the physician and the psychologist, constantly make use of this conception, for they find it impossible to make progress in the understanding of their problems without it. That fact gives the conception a claim to a more serious consideration than it has commonly received from the physiologists."

Dr. MacDougall has done great service to neurology by rendering the conception of nerve-energy as concrete as possible; it might be best to give his own words. "I think that for the present it may be best conceived as a fluid, and I propose that this fluid shall be called neurin. Just as the two-fluid theory of heat, the two-fluid theory of

electricity, and the corpuscular theory of light furnished probably the most useful working conceptions for the sciences of heat, electricity and light at certain stages of their development, so neurin may, I think, be most usefully conceived as a fluid in the present state of neurology, and I think it would be unwise to attempt to regard it as a variety of one of the forms of energy known outside the animal body, although it is easy to discover points of resemblance to both electricity and magnetism. As Barker writes, 'it is by no means impossible that in the nervous system forms of energy are concerned which do not exist outside the animal body, and which yet remain to be recognised and studied.' And we, may, perhaps go even further than this and say that the existence of some form or forms of energy may be assumed with a very high degree of probability, for since, as far as we know, consciousness is only associated with transformations of energy within the living animal body, the forms of energy concerned must be of a highly special and peculiar nature. I will therefore sketch in rough outline a scheme of the part that the fluid neurin seems to play in the workings of the nervous system. In virtue of its normal, vital activity, every

neurone continually produces neurin in small quantity; and the neurones connected with the sense-organs and surface of the body generally, are almost perpetually played upon by feeble stimuli that excite them to the production of neurin in rather large quantities. Neurin tends always to flow from a place of high potential to places of lower potential. The neurin so produced, therefore, tends continually to flow from afferent to efferent neurones, in virtue of the higher potential of the sensory neurones, and of the valve-like nature of the synapses, passing across the synapses by a sort of leakage, and so escaping by the efferent nerves into the muscles as a continuous, gentle stream maintaining that state of continued, gentle contraction of the muscles which we call their tone. It is possible that the slow leakage across synapses is the basis of that obscure affection of consciousness which has been called general sensibility, and forms the groundwork of the psychological self."

If, then, the central nervous system be a source of energy and a cistern whence it is distributed to the tissues, it would be satisfactory if we could find a substance which could be regarded as the physical basis of this

nerve-energy. Through the labours of the microscopists and the great improvement in the colouring and rendering visible of the structural details in nerve-cells, such a substance has been found.

If we prepare a nerve-cell from any part of the nervous system according to a particular method shown to us by Professor Nissl, of Heidelberg, we see that in the depths of the cell, besides the nucleus and certain very fine fibrils, there exist certain characteristic, prismatic bodies stained a deep blue. These bodies are called the granules of Nissl; their presence, and their shape, their outline and the depth of artificial colour characterise a normal nerve-cell. Now, if we examine by the same method nerve-cells which have been either naturally or artificially fatigued—unduly stimulated—we notice that the Nissl granules are less obvious, of irregular and indistinct outline, are pale in stain, in fact, not characteristic. The facts before us, then, are: rested, fresh, "fit" cells have well-formed granules; fatigued, overworked cells have used-up-looking granules; the inference from this state of matters is that the presence of normal granules is associated with the capability to put out nerve-energy, and the

presence of partially destroyed granules is associated with the state of fatigue; the state of having put out energy.

We seem justified, therefore, in saying that the granules are the physico-chemical basis of nerve-energy, are energy-producing (or dynamogenic). Numerous experiments have been made which have shown that in every case where natural or artificial fatigue has been established, the granules of Nissl have shown a wasting away (chromatolysis). The experiments have been on such lines as these: to compare the nerve-cells of a sparrow which had been flying about all day with those of a sparrow killed the first thing in the morning. Or one may stimulate one eye of an animal with light while the other one is covered up, and then compare the state of the granules in the sensory centres for vision corresponding to each eye respectively. The former is a case of natural motor fatigue, the latter one of artificial sensory fatigue, but both show the same thing, partial solution of the granules in the cells that have been active as compared with the cells that have rested. We therefore speak of an energy-producing substance (kinetoplasm) in the nerve-cells. Now this connection between granules and nerve-energy

is not without analogy in other physiological processes. It has been long known that gland-cells when exhausted are relatively devoid of minute granules with which they are seen to be crammed when the cells have rested. Here again the facts are, cells that have not secreted but are ready to do so, are filled with granules; cells that have secreted —given out something—are poor in granules; the granules must be the precursors of the secretion, whether saliva, or gastric juice or perspiration. The analogy with the nerve-cell is very close; granules, capability for exertion; granules, capability for secretion; therefore granules in nerve-cells and nerve-energy are causally connected just as granules in gland-cells and secretion are.

But further: these granules in both cases have arisen either from the nucleus or been produced under its directive influence: in both cases as the granules disappear, the nucleus shrivels and looks used-up: as the granules re-appear, the nucleus looks normal again. Now it is very well established that the nucleus presides over the nutritional changes in the living cells, directs its upbuilding (anabolism) and its disintegrative changes (katabolism). That portion of any cell

separated from its nucleus dies, that part of the neurone separated from the nucleus of the nerve-cell dies.

That the nucleus should produce the granules of Nissl in nerve-cells is entirely in agreement with its functions in cells which are not nerve-cells.

Still further, the chemical composition of the nucleus of the nerve-cell and of the granules of Nissl is very similar: a high percentage of phosphorus characterises both. Here at last we see where the phosphorus absorbed from the food goes, what it helps to form. We have been long told that there is much phosphorus in our nerves, that we ought to take phosphatic foods and eat fish which contains much phosphorus in order to build up a strong nervous system. There is the proverbial grain of truth in it. Food containing phosphorus is certainly necessary, especially during the early years of life to build up a robust nervous system. Nature gives us such food in the lecithins, substances of highly-complicated chemical constitution found especially in milk and in the yolk of eggs. "No phosphorus, no thought," was at one time a favourite saying, and it is true as far as it goes, but it made people think

that phosphorus was the only thing they needed. Lecithin has much in it besides phosphorus, and all the other things are necessary. People have rushed off with the notion that they can stuff the nervous system with phosphorus, overfeed it with phosphorus, and make it exceptionally strong, just as you can overfeed a Christmas ox and make him exceptionally fat. This is a mistake—you cannot overfeed the normal nervous system with phosphorus or with any other element, just as you cannot stuff into any tissue or organ more of a given substance than it has its own chemical affinity for fixing—be it iron, lime, nitrogen, or even oxygen. If, however, the nervous system in question has been allowed to get into an underfed, poor condition, then high phosphorus (lecithin) feeding is good for it, just as, if a person is anæmic more iron than is normally present in food is good for her, or if a person is asphyxiated, pure oxygen is good for him.

Unfortunately, nerve starvation is a real thing, and fraught with momentous consequences: the high feeding of the nervous system is necessary: all good food influences the nervous system beneficially: nervous tissue in particular needs food of a fatty nature,

Nerve starvation is a real thing, and is the cause of low nerve tone and neurasthenia; it needs treatment by generous feeding. But if plenty of good food builds up the nervous system and makes it capable of effort, we see that the nerve-energy must come from assimilated food: physiologically this must be so. The starved man may be desperate, but he has no strength of nerves or of muscles. It has been said that if the starved masses in the great European cities could only acquire nerve-tone through being fed up for a week, there would be a revolution. Bad hygiene, alcohol and nerve-starvation have rendered them so unfit for effort that they remain as they are in their miserable surroundings; but a little more nerve-force and some organisation, and the course of history might be changed!

Fatty food, especially in the plastic stage of the organism, is most valuable in building up the nervous system, for much of the substance composing the nervous system is chemically of a fatty nature. Fat people are rarely "nervous" in the sense of having irritable nervous systems; but we must not jump to the conclusion that because a person is fat his nerve-centres are necessarily well

nourished. There is more than one kind of obesity, some kinds do not indicate good nourishment; but as a rule it is lean people who are nervous. This is what is alluded to by the author of "Julius Cæsar," when he says—

> "Let me have men about me that are fat;
> Sleek-headed men and such as sleep o' nights:
> Yond' Cassius has a lean and hungry look:
> He thinks too much: such men are dangerous."

Closely bound up with the conception of neurin is that of potential of nerve-force. The conception of potential is borrowed from the science of electricity where potential is driving force or electro-motive force. Potential of electricity is contrasted with its quantity; you can have much electricity at a low potential, and you can have a little electricity at a high potential. Potential answers to head of pressure in the flow of water, to temperature in the transference of heat. Water flows from places where there is a "head" of it; from a cistern to lower levels; heat passes from a body in which the temperature is higher to that in which it is lower, but the quantity of heat in the smaller body is very much the smaller. A river flowing through an almost flat valley runs at a low

potential, although it may be a very large river indeed, whereas a mountain torrent, with perhaps only a millionth part of the water, rushes over its steep bed with far greater potential. Energy is the capacity for doing work, potential is the rapidity or intensity with which that work is done. A pebble fired from a catapult breaks a window, not because it does much work, but because it does a little at a high potential; a heavy garden roller pushed along a flat road would do far more work, overcome much more resistance, but it would do it much more leisurely, that is, at a much lower potential.

Now some people do their nerve work at a high potential, while others do theirs at a low. The stone-breaker who sits by the road side and in a leisurely fashion gets through the pile in front of him, is working at a low potential; if you give him time enough he will do a good deal of work, but he objects to being pressed; whereas the energetic amateur set down before the same task could do the same amount of work in a fifth of the time, that is at a much higher potential. Potential is not a measure of the quantity of nerve-work done, it is a measure of the vigour with which that work can be done, the degree

of intensity which can be put into that work whether much or little. We know people who do little things energetically, and we know people who do great things in a slow fashion.

A medical writer on the nervous system thus alludes to potential without using the term—"There are those who make little nerve-force at the best of times, and although their brain power never rises above mediocrity or something lower, they yet suffer in the same way as those more highly endowed, but at an altogether lower pressure along the whole line." What this writer calls "pressure" is usually known as potential.

We ought now to be in a position to look into certain departures from the usual health of the nervous system, not so much those well recognised aberrations in which consciousness is involved—the manias, or insanities, and the like—but abnormal conditions grouped as forms of "nervousness" depending on some alterations in the properties of the neurones.

The word "nervousness" being a non-technical term covers a multitude of heterogeneous aberrations from the normal neural behaviour.

Before commencing our analysis of nervous-

ness, let us recapitulate the properties of the neurone.

1. Affectability; that property in virtue of which the neurone responds to a stimulus by discharging energy (neuro-dynamogenesis) and by conducting impulses (conductivity).

2. Functional inertia; that property in virtue of which the neurone does not at all times respond to stimulation, does *not* discharge energy, or can convert either one sort of rhythm into another or a constant stimulus into a rhythmic.

Nerve-energy or neurin is that real but hitherto imperfectly recognised form of energy produced in neurones and capable of stimulating either other neurones or peripheral tissues to activity. Its impinging on a living tissue (innervation) is a factor in the maintenance of that tissue's tone (trophism): this neurin may be exhibited in large or small quantity and at high or low potential.

Since "nervous" means in ordinary parlance so many different things, it will be best for us first of all to get some idea of what is meant by "neurotic," and then we may be able to bring some forms of nervousness into their places in a more or less complete scheme of the neurally abnormal. The term "neuro-

sis" strictly means the functional activity of a neurone, that is, the passage of impulses over it. Some neuroses are accompanied by psychoses, that is, states of consciousness. Thus an emotion is the psychosis of which the discharge of nerve-energy is the neurosis.

This is, however, not the ordinary or medical use of the word, which is rather different. In medical language a "neurosis" means any neural activity of an abnormal character in quality or in quantity, whether it involves consciousness or not. A neurosis in this sense is an activity of the central nervous system, either too energetic or not energetic enough, at too high or too low a potential. A neurotic person is a person in whom the nervous system bulks functionally too largely. Usually it is activities under rather than above the normal, that are called neurotic, but there is no sanction for this except use and wont. Neuroses are those alterations of bodily function in which the neural activity intrudes too much, or on the other hand, is deficient; conditions in which the nervous system is too active or not active enough. There are, therefore, really positive and negative neuroses, that is, there are neuroses by excess and neuroses by defect. Almost

any neural abnormality may be regarded as a neurosis. This is the implication in such a book as *On Common Neuroses or the Neurotic Element in Disease*, by Sir J. F. Goodhart, M.D.

By a neurotic person the physician most frequently means a person whose nerve-centres are too affectable; a person whose reflexes are too easily elicited, whose emotions are too easily aroused, whose inhibitions are too weak. To this extent, the neurotic person is the nervous, in the sense of "excitable," person of popular language. By a neurosis the physician means such occurrences as blushing or blanching too easily; perspiring, trembling, having reflex convulsions, reflex asthma, etc., under circumstances when the average person would not have them. In all these statements as to neuroses and neurotics we have before us some type which we regard as normal, as the average neurally, any departure from which is called neurotic. Thus we shall find that departure from the average type of nervous system, namely genius, frequently called a neurosis. Many geniuses have been highly abnormal neurally. Possibly so affectable a nervous system as the genius must be possessed of could not be other than a departure from the dead level of a mono-

tonous uniformity. It is of the essence of the neural constitution of the painter, the poet, the musician, to be so responsive to environmental influences, to have such susceptibilities, such powers of expression in paint, words or tones, that he must of necessity have an abnormal or supernormal nervous system: to this extent genius is a neurosis.

No doubt it would not do for every one to be a genius; the work of the world has to be done by normal, average, commonplace people. It is unquestionably true that many geniuses have been people of unstable nervous system; they have been eccentric in a high degree, irritable, wayward, difficult to live with, to co-operate with, to advise.

Large numbers of neuroses are really reflex actions too easily elicitable. Suppose there are twenty people in a room, and the door bangs, three of them may jump up from their seats, or give a gasp or flush, while the seventeen others merely turn their heads in the direction of the sound; the three compared with the seventeen are neurotic relatively to the assembly they find themselves in, but they might not be deemed neurotic in a meeting of Anarchists. Or take the case of a piece of good or bad

news told to a large family, the normal members take it more or less calmly, while the neurotic are thrown into transports of joy or grief, as the case may be; they are unduly affectable as compared with the rest. These neuroses are, then, the results of too much affectability of the nerve centres, which are too easily fired off; but neither the nerve energy nor its potential need vary very much from the normal; it is affectability that is excessive, the centres are too irritable and therefore unstable: in common parlance such people are "jumpy."

The expressions of central irritability may, of course, be very different; it depends on the particular centre fired off and on the particular kind of tissue fired at. Ease of response to a stimulus is one thing, the amount of energy liberated by a stimulus (releasing stimulus) is quite another thing. The same amount of pull will fire off a popgun and the largest cannon, but the amounts of energy liberated by these equally excitable mechanisms are incomparably different. Two centres may be equally affectable, one may produce a sneeze, the other a murderous blow. One type of nervousness, then, is the neurosis of deficiency, the deficiency being that the

centres have too little resistance, their functions are too easily called forth, they respond to stimuli too slight to affect normally affectable cells. " Irritable weakness " is the name sometimes given to this condition. Since the centres are so easily discharged, they never accumulate energy to quite the normal amount. As to motor centres, they tend to discharge too easily, so that we have all sorts of restlessness, fidgeting and fussiness. This sort of thing is almost universal in children, so much so that it would be a misnomer to call it neurotic. Their nervous systems are still plastic, are not yet consolidated, their inhibitions are only partially established, so that the neurin flows over into the muscles too easily (motor overflows); too easily as compared with the stable nervous system of the adult. The systems of children are notably unstable, their heart-rate can be accelerated twenty to forty beats per minute with the greatest ease, their temperature will jump up a degree or two with very slight provocation. Children have the instability of the imperfect, the non-consolidatedness of that which is in the process of becoming. When those motor overflows are distinctly pathological, then we have the disordered

conditions of chorea (St. Vitus' dance), and other exhibitions of inco-ordinate and ataxic muscular behaviour.

The next type of neurotic person we might take up is that called "neurotic" in particular. This temperament is the energetic or nervous found in those persons who cannot rest, and yet who are rarely tired or, at any rate, rarely aware of fatigue. It is the temperament of the successful business or professional man; the very active man physically and mentally. It is doubtful whether one should regard it as abnormal at all; neurotic it is, if by neurotic we mean that the nervous system predominates in the functional whole. It is only on the purely statistical aspect nationally that we could call the essentially nervous temperament abnormal, for, of course, the majority of nervous systems are average or commonplace. It seems, however, absurd to classify the nervous systems of our most successful lawyers, actors, politicians, doctors, surgeons, financiers, newspaper editors, preachers and so on, as abnormal. They are *super*-normal, above the mean in intellect and in neural capacity. Doubtless the exaggerated form of this type is not healthy; but the not extreme form is characterised

by good qualities, the reaction-time is short, the neurin is of considerable volume and of high potential. It is when the cerebral innervation is deficient that this type is on the borderland of the unhealthy; when the man or woman is living at too high a pressure, too fast neurally, that there may come, and very often does come, the nervous breakdown, the collapse. Then we read in the newspapers that Mr. So-and-so, suffering from overwork, has been ordered off on a long holiday. The wise men in this group know how far to go: extremely energetic, they are yet sensible enough to understand, or they have learnt by experience, that they must take due rests or holidays from time to time to relieve the strain. It is very evident that the devices of science pressed into the service of modern society have greatly increased the possible causes of over-pressure and strains on nerves.

Neuroses are not confined to trifles; some of the most serious afflictions of mankind are neuroses; take the case of asthma, it can make the lives of some people burdens grievous to be borne. Asthma is a typical reflex action. Some people will have an attack of asthma if they have an attack of indigestion, or if

they smell new paint or a particular kind of flower, or if they hear bad news. Their friends call them nervous; so they are, for they are neurally abnormal; they are liable to exhibit certain reflex actions (excito-muscular or sensori-muscular) from irritations which, in the vast majority of people, do not call forth these actions. The muscles involved are those tending to close the bronchial tubes and therefore prevent the entrance of air into the depths of the lung. According to its source of irritation, an attack of asthma is an excito-, sensori-, emotio-, or ideo-motor reflex action; but it is a typical neurosis. We now see that a neurosis may only be a reflex action of abnormal character or at an unusual time. Reflex actions involving a raising or a lowering of tissue-tone which, under certain circumstances, may constitute neuroses, were recognised in their relation to disease as long ago as 1848, by a far-seeing Scottish physiologist, John Reid (b. 1809, d. 1849). The whole passage is given, as its spirit is so far ahead of its time in physiological psychology :—

"The emotions of hope and joy . . . promote the capillary circulation in the surface of the body and the elimination of the necessary secretions, and thus render

the body capable of withstanding the causes which excite disease and of resisting it when once formed. On the other hand, the depressing passions such as grief, anguish and despair, by enfeebling the capillary circulation and diminishing or vitiating the secretions, favour the agency of the causes which induce disease and impede the operations of those actions by which the body may get rid of its maladies. . . . It is not unusual to find an army when flushed with victory and elated with hope, maintain a comparative immunity from disease under physical privations and sufferings which, under the opposite circumstances of defeat and despair, produce the most frightful ravages."[1]

Thus did John Reid in the language of the middle of last century describe positive and negative metabolic reflexes which are physiologically what in practical medicine are called "tropho-neuroses" (neuroses having to do with trophism or nutrition).

The neuroses, as we may well believe, play a great part in conditions for which people seek medical advice, and they are probably as difficult to treat as any diseases about which the physician is consulted. Neurotics are a large source of the quack's income. Dr. Goodhart writes :—

"It is my conviction, then, forced upon me by the experience of now many years, that the maladies which owe their origin to a faulty action of the nervous system are of more frequent occurrence in practice than are even

phthisis, heart disease, Bright's disease, or organic hepatic diseases, though these are in no small number."[1]

The last type of nervousness we shall take up is that of deficiency of neurin, and its exhibition at an unduly low potential. This is the functional opposite of the nervous type described a few pages back; it is neural enfeeblement, neurasthenia, that is, nerve-not-strength. In its severer degrees neurasthenia is a disease, and it occupies much space in contemporary medical literature. As this work is not a text-book of pathology, abnormal mental states are alluded to only in so far as they illustrate how the nerves work. According to some authorities, the minor degrees of neurasthenia are exceedingly common, and, in fact, constitute *the* disease of of civilisation, the disease of Europe and America. It is characterised by chronic fatigue or by the liability to be very easily fatigued, and by having no "staying power." It has been frequently remarked that, for instance, the young women of the present time stand the fatigues of a day's shopping, sight-seeing, "calling," travelling, and so on much less perfectly than their mothers or grandmothers did. They collapse more easily, and have to have recourse to tea or ices after

exertions which would have left their ancestors unaffected.

Both the upper and the lower classes show the signs of neurasthenia, so the physicians tell us. They point us to other signs of low nerve-power; the restlessness of modern life, the inability or disinclination of so many people to read anything more serious or "heavy" than the magazines of fiction.

People nowadays must have more frequent changes of occupation than formerly, their interest in any one thing flags quickly, they have great difficulty in concentrating their attention on any given subject for more than quite a short time. Thus we have the immense and growing popularity of music halls, where the programme is changed every few minutes. Men as well as women show these signs of minor neurasthenia.

Now, while a great deal of this indictment against the modern nervous system may be accurate, we have to remember that the conditions of modern city life are vastly more fatigue-producing than at any other time. The mere increase in the volume of noise of the traffic constitutes a sensory bombardment which in itself, and apart altogether from the strain to the nervous system in avoiding

accidents, is intensely provocative of fatigue of the centres. Of course, the implication is that these centres are subnormal as regards their energy and its potential, and that a degree of fatigue which would not depress normal centres does incapacitate these weaker ones. The mere fact that the modern girl is more athletic than her mother and lives out of doors more is not entirely incompatible with her being neurasthenic. We must not trespass on the field of medicine more than to point out that neurasthenia can affect centres other than those for muscles. For instance, there is that feeble innervation of the gastric glands which constitutes a form of indigestion—atonic dyspepsia. Assuming that neurasthenia exists, what are the causes that are producing it ?

The agreement of opinion is that some of the causes are inherited, and some are acquired, operating from the environment. The inherited conditions leading to low nerve-tone are the result of bad hygiene and alcoholism of parents, more especially of the mothers.

The causes operative during life are: unsuitable infant feeding, too early mental education, too little sleep for children, insuffi-

cient ventilation ; city noise ; decayed teeth, bad digestion, and consequent absorption of poisons from mouth and intestine.

A fuller discussion of the historical and national aspects of neurasthenia is to be found in my lecture on " National Degeneration," published in 1909.

CHAPTER X

SOME REFLECTIONS, PRACTICAL AND THEORETICAL

From what we have learnt in the preceding pages it is plain enough that the nerves and nervous system are real though unseen, as real as the heart, the muscles, the glands, or any other part of our bodily frame. It has been too much the tendency in the past to regard the nervous system as something remote from the life of the body, to regard the vehicle of the soul as not a protoplasmic system, as much as the digestive is, and consequently to forget that a strong nervous system, a strong character, and a strong mind all actually depend on good blood. Poor or poisoned blood cannot support a robust nervous system, and unless the nervous system is vigorous, character, emotions, thoughts, will, cannot attain to adequate development.

The transcendent nonsense of the post-impressionist painters arose from absinthe-

poisoned blood. Their blood was abnormal, their nervous system was abnormal, their painting was abnormal; this series looks very like one of cause and effect. Pure blood, pure thoughts, is not a wholly misleading aphorism. But pure blood is recruited from pure food, and pure food unless digested well will not contribute to good blood. Thus, beginning with the food, we are forced to acknowledge that a healthy mind and normal morals depend, to a large extent, upon the so-called "humble" digestive organs. This lowly basis of morals is not the one usually emphasised, but it exists for all that.

The dependence of the nervous system on the activities of other systems in the body has of late years occupied the attention of physiologists with very interesting results. One thing we have learnt is that no one system is self-sufficient, that if one suffers, all suffer; and we have learned that something manufactured at one point may serve some very useful purpose at quite a different place. In particular it has been found that certain glands in the body whose function was previously unknown, have a very potent influence on the growth, nutrition and well-being of the nervous system. Thus, if the

little gland in the front of the throat—the thyroid—is diseased, as it is in goitre, then not only do the skin and other tissues become diseased, but the central nervous system suffers very gravely, and the child develops symptoms of imbecility and remains throughout life a poor, stunted, mis-shapen, mindless creature. Feeding it, however, on thyroid glands taken, for instance, from the sheep, soon clears up the condition and restores it physically and mentally to the normal. A serious disease of adults connected with insufficient activity of this gland, reduces the nervous system to a condition of great enfeeblement which is entirely cleared off by thyroid feeding. Evidently, then, this thyroid gland manufactures something which getting into the blood can influence for good the nerves and nervous system. The something which the gland contributes to the blood is called an internal secretion. When the gland has become diseased or has become a tumour, the nervous system suffers more or less definitely because the secretion is lacking. Besides being in a condition of deficiency, the gland may also be in a condition of excessive activity, and when this is so, the nervous system is again injuriously affected,

this time by being irritated in certain parts and stimulated to over-action. The heart's rate is raised, the eyes protrude, the pupils are dilated, and the patient looks as though he or she had had a severe fright.

Other glands, small and ductless, known as the supra-renals, also influence the nerves and the muscles. When they are diseased or removed from animals, the heart-muscle and blood-vessels become feeble and of very low tone; much of this state being due to the absence of the healthful influence of the internal secretion of these glands on the heart, blood-vessels and muscles.

Quite lately it has been found that in the lower animals, the emotions of fear and anger and the sensation of pain all increase the activity of these little glands, so that blood taken from an angry or terrified animal, and injected into a quiet one, produces certain results that indicate that its muscles have actually been stimulated. The meaning of this is supposed to be that it now needs greater muscular power to fight or to take to flight, as the case may be. The control experiment with injected blood from a quiet animal or from the angry animal before it was excited, gave a negative result. We are

here face to face with some very curious and subtle influence of glandular tissue on the nerves and nervous system.

A body of which still less is certainly known than any of the glands we have yet spoken of, namely, the pituitary body at the base of the brain, is also believed to be able to exert an influence on the nervous system.

But long before these discoveries were made, physiologists had understood that the development and activity of the sex-glands must have a profound influence on the nervous system, and through it on the character and behaviour. From the very great alteration in character and behaviour in the lower animals from which the sex-glands have been removed, and from other well-known phenomena in the sexual life of animals, we are left in no doubt that it is through the instrumentality of an internal secretion that these glands affect the nervous system. From all the foregoing facts it is evident that subtle chemical influences are at work here which it will be the duty of the bio-chemistry of the future to render plain.

The health of the individual nervous system may be said to be *the* factor in the health of the nation. Robust nervous systems in

the units means robust national character; if the nerves of individuals are poor and toneless, then the nerves of the corporate assemblages cannot be strong. We cannot have properties possessed by the multitude which are not present in each member of the mass. It becomes then a matter of national importance to secure those conditions which will conduce to the best upbuilding of the nervous system in each child. By the dissemination of the knowledge of elementary physiology and hygiene we may bring it about that mothers will know all they should on the subject of infant-feeding before and after weaning, know something of the differences between human and cow's milk, something about the protection of milk from microbial contamination, and something of those conditions which go to strengthen the nervous system and through it the powers of resistance to the agents of infection. Cod liver oil and other fatty foods will figure in the dietary of the delicate child.

Knowledge concerning the immense value of sleep and of the requisite number of hours of it, will be more general, and especially will it be recognised as Dr. Dyke Acland, of London, has so well insisted, that at many

of the public schools in England the hours devoted to sleep are too few. It is already being recognised that either physical or mental work for growing boys or girls before breakfast is not a thing to be encouraged. Attention to diet at school is a much commoner thing than it used to be.

While there has been careful study of the diet, sleep, exercise, mental and moral training of our criminals, inebriates, lunatics and criminal lunatics, and other highly undesirable persons, we have left the physical and mental education of our children to persons very often very badly equipped for those duties. In too many cases we have left our daughters to the unenlightened empiricism of otherwise estimable spinsters, whose ignorance of the physiology of the female organism before, during and after puberty would be pathetic if it were not so dangerous.

Dr. Dyke Acland a few years ago demonstrated to the British Association that the handwriting of school boys deteriorated in proportion as they were deprived of sleep, and improved on their being allowed more time for it. The teacher of the future, trained in school hygiene and in the physiology of the immature organism, will know

something of the meaning of physical and mental fatigue, the exact function of exercise, the importance of rest, that education means the enlightened directing of the growing powers, the supplying of sensory information, the training and restraining of motor activities. He and, still more important, *she* will know that "lessons" may be learned too young, that night-terrors and growing-pains have a definite meaning, that the plastic nervous system can be damaged by mechanical, thermal, chemical and mental agencies through their quality, intensity, or suddenness. The nervous system will be the system pre-eminently for study by the pedagogue; for study in the widest sense, not merely by the methods of Experimental Psychology, valuable as they are, but by the aid of the findings of the most recent physiology. The nervous system will be studied as a system undergoing the longest development of any of the bodily systems, one, at first, plastic and unstable, and subject to the strain and stress of such crises as puberty, competition and the desire to excel, and then as one gradually consolidating as its acquirements are elaborated, assimilated and integrated. The pedagogue of the future will, in a word, explain how

each type of nervous system should be used to the greatest benefit of its possessor, for he will recognise that the end of education is not merely acquisition and absorption, but the knowledge when to speak, when not to act, how to endure. It will be increasingly recognised that what one is, is to a very large extent the outcome of the inherited constitution of one's nervous system, and its inborn powers, properties and potentialities. Education—the environment—can work on this not utterly plastic material, and so fashion the man. Nature gives each one of us the neural clay with its properties of pliability and of receiving impressions, nurture moulds it and fashions it till a character is formed, a mingling of innate disposition and acquired powers. But clay will be clay to the end, and you cannot expect it to be marble.

We shall increasingly recognise that breeding, fineness of temper and amenability to the influences of culture, are as much the outcome of neural molecular dispositions as they are the responses to appropriate surroundings. Style in all its individuality and inimitableness, whether that of the painter, the poet, the preacher, the musician, the actor, or the orator is inherent in their nervous systems,

and is before and beyond the teacher's art. Other people besides poets are born not made. Education, working on the good material which hygiene has provided, will teach, above all things, inhibition. Inhibition is the art of restraining personal immediate tendencies for the good of the individual or the race, and it is best developed in the soundest nervous system. A person, no matter how highly educated otherwise, is a neural monster if he has not inhibition. The lack of inhibition is not the expression of neural strength, but the result of the neural machine having lost its governor. Inhibition is the expression of neural vigour, it is knowing when and where to stop, when not to act, not to speak. It is the art of keeping things within bounds, of gaining moral perspective, of subordinating self and the present for the sake of the race and the future. "Though I speak with the tongues of men and of angels, and have not" inhibition, "it profiteth me," physiologically speaking, "nothing."

GLOSSARY

ADYNAMIA.—Loss of power in muscles.

AFFECTABILITY.—The property or power of responding to a stimulus.

AFFERENT.—Leading into the central nervous system (*A* in Figs. I., IV., VI.).

ARBORESCENCE.—The filamentous endings of a nerve-fibre; some are the beginnings of afferent fibres (Fig. II., 2 and 3); more are the endings of efferent ones on, *e.g.*, muscle, blood-vessel, gland. (*See* Figs. I., III., VII., VIII.)

ASCENDING.—With reference to central nervous system, means either afferent or headward.

ATAXIA.—Inco-ordination of muscles as occurs in cerebellar disease.

ATONIA.—Loss of tone in muscles.

AUGMENTATION.—Increase in intensity of physiological activity.

AXIS-CYLINDER (AXONE, NEURAXONE).—The central living core of a nerve-fibre; it conducts nerve-impulses (Fig. II.).

CENTRES (NERVE).—Nerve-cells devoted to the performance of some definite physiological function; sensory centres in cerebral cortex are the physical bases of sensations; motor or psycho-motor centres in cerebral cortex send down impulses for maintaining tone and contractions of muscles.

CEREBRUM.—The brain; as used in this work equivalent to cerebral cortex or grey matter on the outer surface of the brain; it is the physical basis of consciousness.

Cerebellum.—Literally small brain; a mass of grey matter sending fibres to the cerebrum and receiving fibres from the body, especially the muscles via the spinal cord. Its activities do not rouse consciousness; it is concerned with the balancing of the body, that is, its displacements in three directions of space.

Consciousness.—Personal experience or awareness of one's body and the world given in sensations, perceptions; the totality of mental occurrences (thoughts, emotions, memories).

Co-ordination.—The term applied to the harmonious simultaneous action of several muscle-groups.

Cord (Spinal).—That lowest part of the central nervous system which receives nerves from the body, sends out nerves to the body and possesses in its interior many nerve-centres in series.

Degeneration (Wallerian).—The death of nerve fibres on their being separated from their trophic cells.

Descending.—With reference to the central nervous system, means either efferent or tailward.

Efferent.—Leading out of the central nervous system.

Emotio-Motor.—Such physiological activities as are the result of emotion.

Eumetria.—The exact amount of muscular effort to be put forth to accomplish a certain result.

Excito-Motor.—Such impulses as arouse reflex actions unaccompanied by consciousness.

Facilitation.—The making an action easier.

Ganglia or Ganglion-cells.—An old name for nerve-cells.

Grey Matter.—An old term for masses of nerve-cells in the central nervous system.

Ideo-Motor.—Such physiological activities as are the result of ideas.

Inhibition.—Restraint of or diminution in intensity of an action.

Innervation.—The giving out or the receiving of nerve-impulses.

INTERNUNCIAL NEURONE.—One interposed between an afferent and an efferent neurone.

MEDULLATED NERVE FIBRE.—That kind of fibre provided with a fatty medullary sheath; fibres in the central nervous system (white matter) do not also have a primitive sheath; the other fibres do. (White matter = medullary substance.)

MEDULLA OBLONGATA.—That portion of the central nervous system leading from spinal cord towards cerebral peduncles containing some of the most important "vital" centres in the body.

METABOLISM.—Literally exchange of material; in physiology it is a two-phased process; Anabolism is the intake and upbuilding of matter on the part of living substance (protoplasm, bioplasm); Katabolism the disintegration and output of matter.

NERVE-CELL OR NEURONE.—The histological and functional unit of the nervous system; each nerve-fibre is connected by its growth to a nerve-cell (trophic cell).

NORMAL.—A term in physiology indicating the proper or usual health (nutrition) of a tissue, organ or system. Hypo-normal is being below the normal; hyper-normal, being above it; ab-normal is diseased or pathological.

NEURASTHENIA.—Weakness of nervous system.

NEURAXONE.—*See* Axis-Cylinder.

NEURIN.—New term for nerve-energy.

NEURO-MUSCULAR JUNCTION (MOTOR END-PLATE).—The spot where an efferent neurone ends by arborescence on a muscle.

PEDUNCLES (OF THE BRAIN).—The two nerve paths conveying all the fibres respectively to and from the two cerebral hemispheres.

PERIPHERY.—In this work, all the body which is not the central nervous system.

POTENTIAL.—A term borrowed from electricians, denoting the intensity with which nerve-energy is manifested or tissue-work done.

Primitive Sheath or Neurilemma.—The outermost sheath of a nerve-fibre (p.s. Fig. II., *A*).

Reflex Action.—An activity, not requiring consciousness, which is the result of impulses ascending to a centre and exciting it to discharge impulses to the periphery.

Regeneration (of Nerves).—The processes of repair of a degenerated nerve-fibre.

Sensori-Motor.—Reflex actions accompanied by sensations.

Stimulus.—The agent whereby some form of energy is brought to bear on protoplasm; if this application tends to exalt its activity, it is called a positive stimulus; if to depress it, a negative.

Synapsis.—Literally a clasping; the mode of ending of one neurone over some other; the former ends by an arborescence (*S* in Fig. VI.; *B*, etc., in Fig. IV.; *C* in Fig. I.).

Synergism (-ic).—The simultaneous activity of two or more muscle groups.

Synthesis.—The opposite of analysis; the bringing together into a functional unity.

Taxia (or Taxis).—Literally, arrangement; the due co-operation of muscles in maintaining balance or locomotion.

Tone (Tonus or Bio-Tonus).—The normal, healthy condition of tissue nutrition. Hypo-tonus is lowered tone; hyper-tonus is increased tone; atonus is loss of tone.

Vascular.—From vas, a vessel; belonging to the circulatory system (heart, arteries, capillaries, veins).

Vaso-Motor Centre.—The cells of origin of vaso-motor neurones.

Vaso-Motor Nerves.—Nerves distributed to blood vessels.

White Matter.—The name given by anatomists to the medullated nerve fibres on the surface of the spinal cord and inside the cerebrum and cerebellum.

BIBLIOGRAPHY

CLOUSTON, SIR T. S., M.D.—*The Hygiene of Mind.* An admirable account of the physical basis of mental operations.

FOREL, AUGUST, M.D.—*Hygiene of Nerves and Mind in Health and Disease.*

GOODHART, SIR J. F., M.D.—*On Common Neuroses, or the Neurotic Element in Disease.* To be read after Chapter X.

HARRIS, D. FRASER, M.D.—*A Classification of Reflex Actions. Brain.* Summer, 1894. A technical summary of Chapters III., IV., and V.

HARRIS, D. FRASER.—*National Degeneration.* (Cornish, Birmingham.) A popular lecture on neurasthenia; partly historical.

HARRIS, D. FRASER.—*Sleep.* (Cornish.) To be read after Chapter VIII.

LICKLEY, J. D., M.D.—*The Nervous System.* The anatomy and physiology are both well treated, the illustrations are good.

LOEB, JACQUES.—*The Brain and Comparative Psychology.* An interesting work not on conventional lines.

LUGARO.—*Modern Problems in Psychiatry.* Only for quite advanced students.

MCDOUGALL, WM., F.R.S.—*Physiological Psychology.* (Temple Primers.) *Psychology, the Study of Behaviour.* This series. Both important works on the science common to mind and organism.

McKendrick and Snodgrass.—*Physiology of the Senses.* A valuable treatment of the fundamental facts.

Mitchell, S. Weir, LL.D.—*Nervous Diseases.* Popularly discussed, eminently readable.

Morat, J. P.—*The Physiology of the Nervous System.* A presentation of the subject in the light of recent research.

Sherrington, C. S., F.R.S.—*The Integrative Action of the Nervous System.* For advanced students. Based on Prof. Sherrington's recent experimental work.

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